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Cost Comparisons of Selected Technologies for the Control of Sulfur Dioxide from Copper Smelters

PEI Associates, Inc., Cincinnati, OH

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COST COMPARISONS OF SELECTED TECHNOLOGIES FOR THE CONTROL OF SULFUR DIOXIDE FROM COPPER SMELTERS

by

PEI Associates, Inc.
11499 Chester Road
Cincinnati, Ohio 45246

Contract No. 68-03-3197

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The U. S. nonferrous metals production industry is a significant contributor of sulfur dioxide, trace metal, and particulate air emissions. Most of the domestic copper smelting capacity is based on obsolescent technology that is both capital- and energy-intensive and hampered by considerable emission control problems. Because systems used to control sulfur dioxide emissions also must remove particulate contaminants, effective control of total particulate and trace element emissions is accomplished as a "byproduct" of sulfur dioxide control. The sulfuric acid plant, when it can be operated under autothermal conditions, is recognized as the technology of choice for controlling sulfur dioxide emissions from smelters.

Unfortunately, much of the problem of sulfur dioxide control in the nonferrous industry is associated with the weak sulfur dioxide off-gas streams. Because weak sulfur dioxide streams do not permit autothermal acid plant operation, they cannot be economically controlled by acid plant technology. In copper smelting, the major sources of weak sulfur dioxide off-gases are the reverberatory furnace and multihearth roaster, followed by fugitive emissions that emanate from the converter operation, matte tapping, slag tapping, and ladle transfer. The status of development and use of a number of technologies for wet scrubbing and for process changes based on oxygen smelting technologies were evaluated to determine which could be considered promising candidates for near-term application for sulfur dioxide control at domestic smelters. Cost models were developed for those processes believed to be sufficiently promising for such application.

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the impacts of the related pollution on our environment, and even on our health, often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory in Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report presents information on process modifications and off-gas treatment techniques to reduce atmospheric sulfur dioxide emissions from copper smelters. Process descriptions and capital and annualized cost estimates for process changes and add-on control systems are provided. Factors affecting the installation and cost of these systems are also presented.

The information presented in this study will be useful to other Agency components and state agencies in assessing a smelter's plans for complying with emission regulations.

David G. Stephan
Director
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ABSTRACT

The U. S. nonferrous metals production industry is a significant contributor of sulfur dioxide, trace metal, and particulate air emissions. Most of the domestic copper smelting capacity is based on obsolescent technology that is both capital- and energy-intensive and hampered by considerable emission control problems. Because systems used to control sulfur dioxide emissions also must remove particulate contaminants, effective control of total particulate and trace element emissions is accomplished as a "byproduct" of sulfur dioxide control. The sulfuric acid plant, when it can be operated under autothermal conditions, is recognized as the technology of choice for controlling sulfur dioxide emissions from smelters.

Unfortunately, much of the problem of sulfur dioxide control in the nonferrous industry is associated with the weak sulfur dioxide off-gas streams. Because weak sulfur dioxide streams do not permit autothermal acid plant operation, they cannot be economically controlled by acid plant technology. In copper smelting, the major sources of weak sulfur dioxide off-gases are the reverberatory furnace and multihearth roaster, followed by fugitive emissions that emanate from the converter operation, matte tapping, slag tapping, and ladle transfer. The status of development and use of a number of technologies for wet scrubbing and for process changes based on oxygen smelting technologies were evaluated to determine which could be considered promising candidates for near-term application for sulfur dioxide control at domestic smelters. Cost models were developed for those processes believed to be sufficiently promising for such application.

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SECTION 1

INTRODUCTION

Primary nonferrous smelters emitted about 6 percent of the total sulfur dioxide (SO_2) in the United States in 1980. These smelters consisted of 15 copper smelters[1] (largely in the western United States), 5 lead smelters (not including Bunker Hill),[2] and 7 zinc smelters.[3] Several of the copper smelters currently operate on curtailment programs to limit their ambient SO_2 impact.[4]

The potential SO_2 emissions from the 15 primary copper smelters (13 of which are located west of El Paso, Texas) operating at their full capacity of allowable sulfur input [based on State Implementation Plans (SIP's) and potential SO_2 emissions] would be equivalent to those from approximately 124 1000-MW powerplants with SO_2 emissions limited to 516 ng/J (1.2 lb/10^6 Btu) of heat input. The total allowable sulfur input for the 13 western primary copper smelters is 6572 Mg (7244 tons) per day, and the potential SO_2 generated would be 531 Mg (585 tons) per hour. Because some plants control part of their emissions, the total potential SO_2 emitted at this sulfur input is 375 Mg (414 tons) per hour [equivalent to 87.5 1000-MW powerplants with SO_2 emissions of 516 ng/J (1.2 lb/10^6 Btu)]. These relatively high emission levels may contribute to problems of sulfate-related visibility reduction, high ambient air SO_2 concentrations, and acid rain generation in the West.

A review of estimated emissions from U.S. primary copper smelters indicates that a modern well-controlled smelter will emit approximately 3 to 4 percent of the sulfur input as SO_2, whereas all primary smelters combined currently emit 34 percent of their total sulfur input as SO_2. The use of oxygen combined with the minimizing of air infiltration appears to be one of the more effective ways to achieve SO_2 emission control. This approach offers reductions in equivalent energy costs by as much as 37 percent over the conventional, uncontrolled, wet-feed reverberatory/Peirce Smith converter smelting system. This estimated energy saving includes the energy required for both the oxygen and acid plants.

For purposes of considering SO_2 control techniques, the off-gases from nonferrous smelters can be categorized as follows: 1) those with high or strong SO_2 concentrations (greater than 4 percent) that can be controlled by the use of sulfuric acid plants, and 2) those with SO_2 concentrations of less than 4 percent. For a single-contact acid plant, a minimum of a constant 3.5 percent SO_2 would be required for the process to be autothermal; whereas for a double-contact plant, 4 percent SO_2 in the gas stream is required.[5]

Options for bringing weak SO_2 streams under control include the following:

1. Use of either regenerative or nonregenerative gas scrubbing systems.
2. Modification of furnaces to produce a strong gas stream through measures such as oxygen enrichment.
3. Replacement with alternative technology producing strong SO_2 streams and controlled primarily by acid plants.

Although not practiced in the United States, gas scrubbing is used by a few of the smelters in Canada, Sweden, and Japan. Each system is unique to the smelter to which it is applied; that is, it is applied at only one smelter. The selection of the system for a particular smelter was found to be governed by such particular circumstances as the cost of raw materials and the availability of byproduct markets rather than on the technical suitability of the processes.

Upgrading of existing furnace operations to strengthen SO_2 content can be an effective approach to SO_2 control when coupled with an SO_2-recovery or a scrubbing system (e.g., when no market exists for acid, the lower-volume gas stream reduces scrubbing equipment costs). Alternative pyrometallurgical processes are of interest because they produce a strong SO_2 gas stream that can be sent to a sulfuric acid plant, reduce energy consumption, decrease gas stream volumes, and subsequently reduce operating costs.

This report describes and estimates the costs of process modifications that would enable existing copper smelters to increase their SO_2 concentration and make recovery more practicable. Process modifications are described, and estimated installed and annualized costs of an INCO-type oxygen flash furnace smelting process, an oxygen-sprinkle process, and an oxygen-fuel smelting process are presented for model plants. The Outokumpu Oy, Noranda, and Mitsubishi continuous processes are also described, but in less detail.

Whenever possible, existing equipment was assumed to be modified to minimize costs. The plant modification costs include estimates for dismantling and demolition as necessary. Each plant actually has specific needs with regard to arrangement and layout, and thus costs could vary widely. In each case, the acid or oxygen plants were considered to be new units. Existing converters were utilized, and as the copper percentage of the matte increased, the operating costs reflect a reduction in blowing costs and labor. A "greenfield" installation would be more costly than a retrofitted installation because it would entail additional costs for ore handling, blending, and preparation facilities; converters; buildings; services and utilities; rail facilities; working capital; and other items.

A new "greenfield" smelter based on newer smelting technology would show lower capital and operating costs than a plant based on reverberatory smelting at a comparable production rate.[6] In addition, location of a new smelter near a sulfuric acid market would increase sales of this byproduct and improve profitability.

Descriptions and costs of scrubbing weak SO_2 streams by utilizing lime, limestone, magnesium oxide, or citrate systems are also included.

The selection of a process modification and SO_2 control system depends on many complex related factors. These include:

- SO_2 emission limits (e.g., degree of control required)
- Operating costs
- Control and capture of atmospheric emissions of particulates, sulfur dioxide, and other chemicals that are detrimental to the environment or public health
- Improved working atmosphere in the plant
- Availability and cost of fuel and power (current and estimated for the future)
- Market for byproducts from control of emissions
- Disposal of captured emissions if not salable
- Current and expected ore composition
- Turndown capability of the primary smelter furnace and its associated processes
- Cost of various types of conversion equipment and disruption or possible loss of the existing smelting capacity during installation
- Space availability and effect on future operations resulting from the location of processes within or near the existing smelter
- Productivity gains
- Payout time

All these factors must be considered together because they are interdependent. They are also very site-specific, as is the optimum combination of process modifications and control systems.

Table 1 shows the annual operating cost for two smelter process systems based on operating parameters of Kellogg and

TABLE 1. ANNUAL OPERATING COSTS FOR AN ANODE COPPER WET-FEED REVERBERTAORY FURNACE AND AN INCO FLASH SMELTING (RETROFIT) FURNACE--90,720 Mg (100,000 TONS) PER YEAR CAPACITY

[Cost per 0.907 Mg (ton) blister copper]

Item	Quantity or cost identifier	Wet-feed reverb smelter, $	INCO flash smelter, $
Fuel oil[7]	$0.264/liter or $1.00/gal	112.20	14.00
Natural gas[7]	$\$0.088/m^3$ or $\$2.50/1000\ ft^3$	2.26	1.43
Flux[7]	$33.07/Mg or $30/ton	23.31	19.08
Electricity[7,a]	40 mills/kWh	(-0.86)	30.12
Lime[b]	$44.09/Mg or $40/ton	1.72	2.387
Labor	$10.00/man-hour	27.872	23.712
Supervision	15% of labor	4.181	3.557
Maintenance labor	1.875% of capital cost	50.031	41.638
Maintenance supervision	20% of maintenance labor	10.006	8.328
Maintenance materials	2% of capital cost	52.532	44.414
Operating supplies	20% of maintenance	22.514	18.876
Payroll overhead	60% of all labor and supervision	52.254	46.341
Water	Process and cooling	0.27	0.28
Administration and overhead	40% of labor, supervision, materials, and supplies	66.854	56.21
Taxes and insurance	2% of capital cost	37.523	44.414
Depreciation	Straight-line		
° Acid and oxygen plants[9]	10.526%	-	39.284
° Smelter[9]	7.143%	-	37.303
Interest	10% of capital cost	-	89.545
Annual operating cost with steam credit[c]		462.667	520.919
Cost per kg (lb)[c]		0.5100 (0.2313)	0.5742 (0.2605)
Equal operating cost with steam credit, at 7.9 years, per kg (pound)[c]		0.5100 (0.2313)	0.5100 (0.2313)
Annual operating cost with steam credit, depreciation zero after 14 years[c]		462.667	343.478
Cost per kg (lb)[c]		0.5100 (0.2313)	0.3786 (0.1717)
Annual operating cost with steam and acid credit[c]		416.927	457.619
Cost per kg (lb)[c]		0.4586 (0.2080)	0.5044 (0.2288)
Equal operating cost with steam and acid credit at 4.5 years, per kg (lb)[c]		0.4586 (0.2080)	0.4586 (0.2080)
Annual operating cost with steam and acid credit, depreciation zero, after 14 years		416.927	280.178
Cost per kg (lb)[c]		0.4586 (0.2080)	0.3088 (0.1401)

[a] Steam not utilized for preheat, etc.; converted to electricity at 40 mills per kWh credit.

[b] Neutralize sludge from acid plant.

[c] Does not include ore cost.

NOTE: If necessary to neutralize all acid produced, add $0.0739 per kg ($0.0335 per pound) of copper.

Henderson.[7] One is an existing wet-feed reverberatory furnace with Peirce-Smith converters and anode furnaces with an acid plant for the Peirce-Smith converters.[8] The other is an INCO flash smelting furnace (retrofit); this includes new fluid-bed dryer(s), new acid and oxygen plants, and utilization of the existing Peirce-Smith converters and anode furnaces. Both plant capacities are 90,720 Mg/yr (100,000 tons). The utilities and flux consumed were assigned the following cost values:

Oil	\$1.00/gal	(3.785 liters/gal)
Natural gas	\$2.50/1000 ft^3	(28.3 m^3/1000 ft^3)
Flux	\$30.00/ton	(0.907 Mg/ton)
Electricity	40 mills/kWh	
Acid credit	\$20.00/ton F.O.B. at smelter	(0.907 Mg/ton)

Capital costs were updated to January 1983. The costs for ore concentrate and electrolytic refining are not included. Labor and maintenance are based on the operations from incoming raw materials through anode copper and the acid plant, not just the furnace operations.

The items that most affect a new system are depreciation, interest, and the new acid plant. If the existing acid plant is usable, the capital costs of the INCO system would be lower. The INCO system in Table 1 includes a slag milling unit for the Peirce-Smith converters, which may or may not be required.

SECTION 2

SMELTER PROCESS MODIFICATIONS

The smelter process modifications considered in this study are those that will produce blister copper more economically and in a more environmentally acceptable way than the processes currently used at most U.S. smelters. These modifications include one or combinations of the following approaches:

- Use of a rotary or fluid-bed dryer for preparation of concentrate and flux.
- Modifications of a reverberatory furnace to include oxygen-fuel or oxygen sprinkle smelting.
- Replacement of reverberatory furnace(s) with an INCO, Noranda, or Outokumpu Oy type furnace(s) or a Mitsubishi continuous-in-line smelting system.
- Modifications to an existing acid plant(s) to handle either a higher SO_2 content in the gas stream obtained from process changes, or to convert from a single-contact to a double-contact acid plant, or to add a new acid plant.

This section describes these modifications and the costs for converting a conventional reverberatory-based smelting process. A computerized cost estimating model is presented in Appendix A.

BENEFITS OF MODIFICATIONS

Several benefits accrue from process modifications of the conventional reverberatory smelting furnace to incorporate the use of tonnage oxygen smelting processes. The use of tonnage oxygen reduces the fuel energy required for smelting, significantly increases the sulfur dioxide concentration in the smelting furnace off-gas and decreases the quantity of off-gas per ton of concentrate smelted, increases the specific smelting capacity of the furnace, and increases the matte grade (which results in an effective increase in converter capacity). Taken together, these benefits mean greater productivity at reduced labor and energy costs.

Fuel Energy

The following is a list of fuel energy requirements per megagram (ton) of concentrate to produce cathode copper based on a process fuel equivalent of 1 kilowatt-hour (electrical energy) equal to 10,500 Btu, a Peirce-Smith converter having an average SO_2 off-gas of 4 percent by volume, no steam credit for Peirce-Smith converters, and no credit for flux energy value. The wet-feed reverberatory smelting process represents current common smelting practice and is considered to be fairly energy-intensive.

Dryer with electric arc furnace smelting process/acid plant for arc furnace and Peirce-Smith converters[10]	2.450×10^6 kcal (8.819×10^6 Btu)
Wet-feed reverb smelting process/acid plant for Peirce-Smith converters[10]	2.204×10^6 kcal (7.933×10^6 Btu)
Fluid-bed calcine reverb smelting process/acid plant cor calciner and Peirce-Smith converters[10]	1.954×10^6 kcal (7.032×10^6 Btu)
Oxy-fuel smelting and oxygen plant/acid plant for oxy-fuel and Peirce-Smith converters[12]	1.838×10^6 kcal (6.616×10^6 Btu)
Dryer, air preheat, 11.3 percent oxygen enrichment for Mitsubishi continuous smelting and oxygen plant/acid plant[10]	1.540×10^6 kcal (5.543×10^6 Btu)
Dryer with oxy-sprinkle smelting and oxygen plant/acid plant for oxygen sprinkle smelting and Peirce-Smith converters[10,11]	1.466×10^6 kcal (5.276×10^6 Btu) (5.708×10^6 Btu with slag cleaning)
Dryer, air preheat, 2 percent oxygen enrichment for Outokumpu Oy flash smelting/acid plant for Outokumpu Oy and Peirce-Smith converters[10]	1.437×10^6 kcal (5.171×10^6 Btu) (5.603×10^6 Btu with slag cleaning)
Noranda furnace and oxygen plant/acid plant for Noranda and Peirce-Smith converters[10]	1.425×10^6 kcal (5.131×10^6 Btu) (5.563×10^6 Btu with slag cleaning)
Dryer with INCO-type and oxygen plant/acid plant for INCO and Peirce-Smith converters[10]	1.390×10^6 kcal (5.005×10^6 Btu) (5.439×10^6 Btu with slag cleaning)

Table 2 presents a comparison and breakdown of the energy required for conventional and selected modified smelting techniques with a double-absorption/double-contact acid plant. The gases from the Peirce-Smith converter are estimated to average 4 percent SO_2 by volume in this comparison. Again, the wet-feed reverberatory process requires the most energy.

Sulfur Dioxide Concentration

The use of oxygen in smelting reduces (and in some cases eliminates) the fossil-fuel requirements, increases sulfur dioxide concentration in the off-gas, and decreases off-gas flow. This use of oxygen reduces the energy and equipment size required to handle the off-gas and can result in as much as a 30-fold reduction in gas cleaning equipment size. Thus, increased sulfur dioxide concentration lowers the cost of control equipment and the power requirements of sulfur recovery. For example, a sulfuric acid plant that controls a 4 percent SO_2 stream costs about 1.8 times as much as one handling a 12 percent stream for the same daily acid production. Power required per unit of sulfuric acid by the plant controlling the 4 percent stream would be 91.7 percent greater than that required by the plant controlling a 12 percent SO_2 stream, for either a single or double contact plant.[10]

Lower Operating Cost(s)

With increased oxygen use, operating costs would be lowered because the off-gas stream volume would be smaller and the SO_2 content would be higher. The use of oxygen or oxygen-enriched air decreases the amount of nitrogen passing through the system. Because nitrogen dilutes the product gas stream, significant savings can be achieved in the capital and operating costs of the off-gas handling and cleaning systems through large reductions in the nitrogen content of the combustion gas entering the smelting furnace.

Specific Smelting Capacity

The use of oxygen in the smelting step also increases the concentrate throughput for a given size furnace, as shown in Table 3. These values would vary somewhat, depending on concentrate composition.

TABLE 2. ENERGY COMPARISONS FOR VARIOUS SMELTING TECHNIQUES (10^6 Btu PER TON OF CONCENTRATE)

Facility	Wet-feed	Calcine	INCO	O-O-S	Oxy-fuel
Storage, blending, crushing (material handling)	0.147	0.147	0.147	0.147	0.147
Roaster (material handling, blowing, collection, gas handling to acid plant, fuel)		0.014 0.093 0.065 0.052 0 -0.113 steam credit			
Green-feed (Partial drying, material handling, fuel blowing, gas handling)					0.014 0.250 0.021 0.045
Fluid-bed dryer material handling, fuel, blowing, gas handling)			0.014 0.273 0.070 0.073	0.014 0.273 0.070 0.073	
Reverb furnace (material handling, blowing, fuel, steam, gas handling, steam credit)	Above 0.026 4.808 0.490 0.169 1.795	Above 0.016 3.457 0.307 0.095 -1.107			
INCO flash furnace (material handling, oxygen, gas handling fuel)			Above 0.810 0.011 0		
Oxygen-sprinkle smelting (material handling, oxygen, gas handling, fuel)				Above 0.846 0.033 0.720 -0.560 steam credit	
Oxy-fuel (material handling, gas handling, oxygen, fuel)					Above 0.095 0.014 blowing 0.810 2.574 -1.107 steam credit
Peirce-Smith converter (material handling, blowing, fuel, gas handling)	0.991	0.769	0.603	0.603	0.769
Anode furnace (material handling, blowing, fuel)	0.391	0.391	0.391	0.391	0.391
Electrolytic refining	1.418	1.418	1.418	1.418	1.418
Acid plant DC/DA MTPD (STPD) Slag cleaning opt.	1.288 544 (600)	1.315 649 (715)	1.195 813 (896) 0.434	1.250 792 (873) 0.432	1.270 787 (868)
Total (with acid plant and without slag cleaning)	7.933	7.032	5.005	5.276	6.616
Credit for acid per ton concentrate ($20.00/ST acid F.O.B. at smelter)	$-12.00	$-14.30	$-17.92	$-17.46	$-17.36

TABLE 3. COMPARISON OF FURNACE CONCENTRATE THROUGHPUT

System	Concentrate throughput	
	Mg/m^2 per day	$Tons/ft^2$ per day
Conventional wet-feed	2-3	0.2-0.31
INCO flash smelter	13	1.33
Oxygen-sprinkle	3.95	0.4
Oxy-fuel smelting	~5.4	~0.55

Thus, for a given furnace hearth area, concentrate feed could be increased by a factor of about 2 to 6, depending on the type of furnace modification and degree of oxygen enrichment.

Higher Matte Grades

Blowing time in the Peirce-Smith converters would be reduced due to the higher matte grades achieved with oxygen enrichment, i.e., converter time for blowing of matte to blister copper. If the time required to convert matte to blister copper is "t" for 35 percent copper matte, for 42 percent copper matte it becomes 0.8 "t" and for 50 percent copper matte, 0.65 "t".[13] In addition, fewer converters are required to produce the required tonnage. A savings would be realized in blowing time, energy, and labor, and the production capability would be greater.

REVERBERATORY FURNACE SMELTING

A typical conventional reverberatory smelting furnace can vary in size from 30.5 to 40.2 meters by 7.8 to 12.2 meters (approximately 100 to 132 ft long by 25.5 to 40 ft wide) and can handle approximately 944 Mg/day (1040 tons/day) concentrate.[10] In domestic practice, the reverberatory furnace (Figure 1) receives its copper ore concentrate as a "wet-feed" or as calcine from a multihearth furnace (Figure 2), or a fluid-bed roaster (Figure 3). The copper concentrate can be charged to the reverberatory furnace through the furnace roof or sides by means of conveyors, gravity, etc. The burners for fuel and air are introduced in the end wall (near the matte tapping and at the opposite end from the off-gas takeup and slagging ports). Converter slag is also returned via this same burner end wall. Matte is tapped on either or both sides of the longitudinal walls of the furnace. Slag is usually removed in the area of the uptake or end wall of the furnace opposite the converter aisle. The reverberatory slag containing less than 0.5 to 0.6 percent copper[14] is discarded, and the matte is carried in ladles to the Peirce-Smith converter (Figure 4).

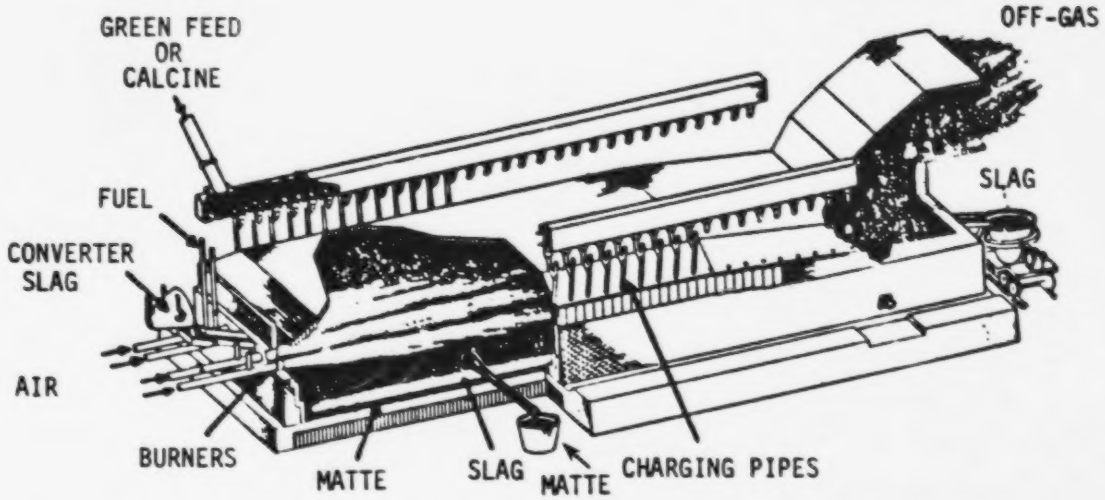
GREEN FEED
OR
CALCINE
OFF-GAS
SLAG
FUEL
CONVERTER
SLAG
AIR
BURNERS
MATTE
SLAG
MATTE
CHARGING PIPES

Figure 1. Reverberatory smelting furnace.[15]

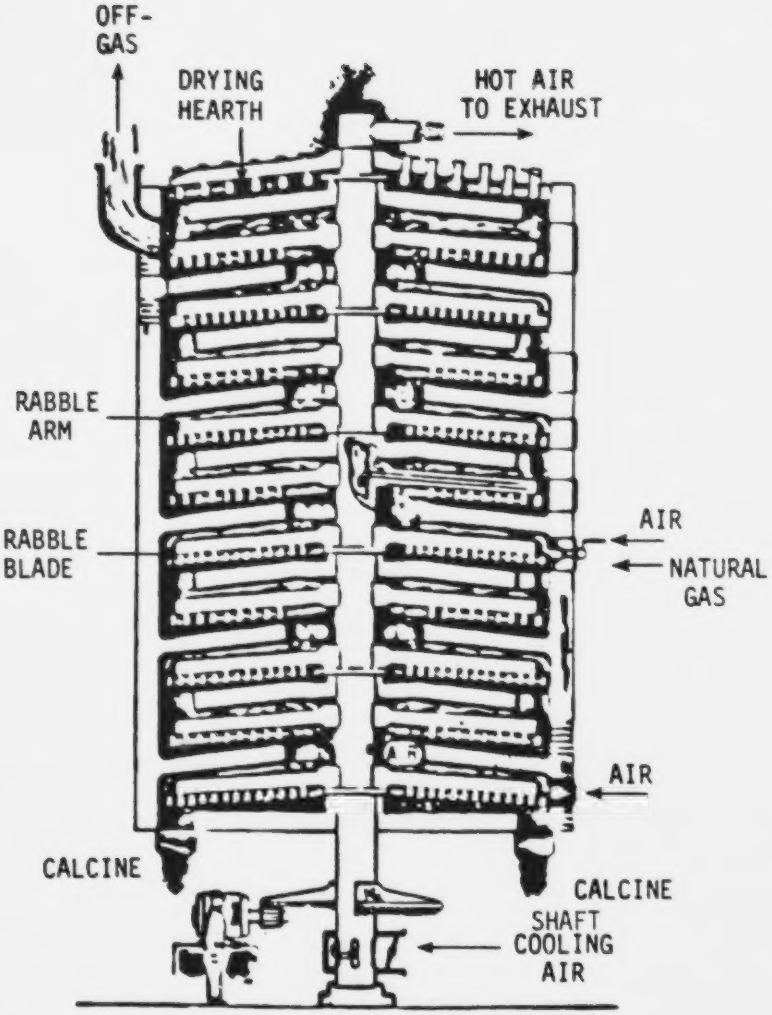
OFF-GAS
DRYING HEARTH
HOT AIR TO EXHAUST
RABBLE ARM
RABBLE BLADE
AIR
NATURAL GAS
AIR
CALCINE
CALCINE
SHAFT COOLING AIR

Figure 2. Multiple-hearth roasting furnace.[15]

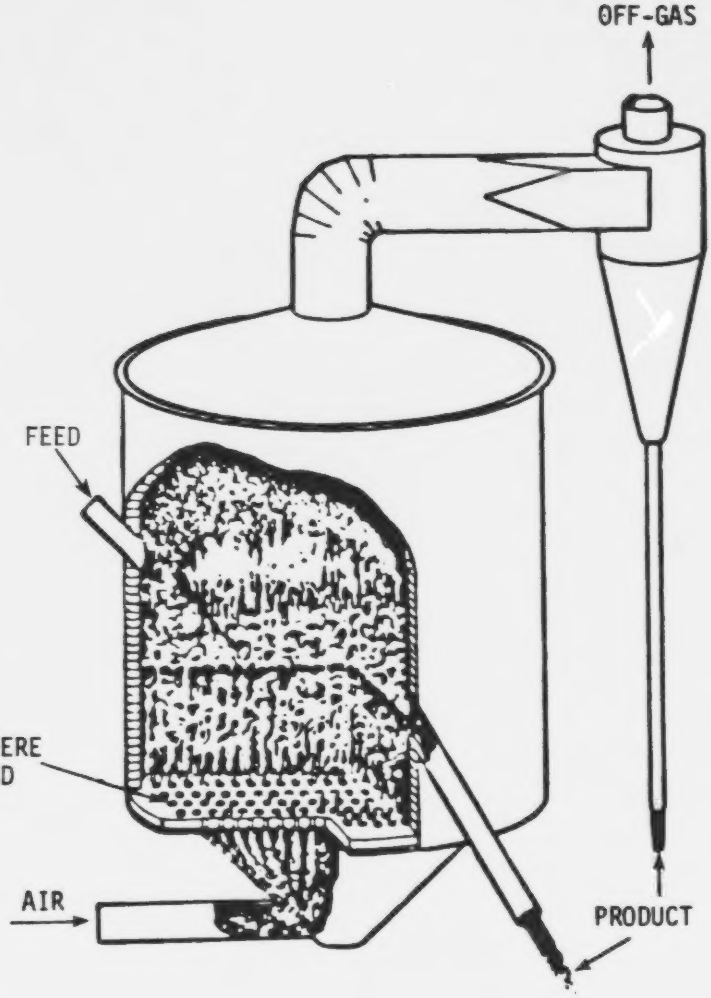
OFF-GAS
FEED
TUYERE HEAD
AIR
PRODUCT

Figure 3. Fluid-bed dryer or roaster.[15]

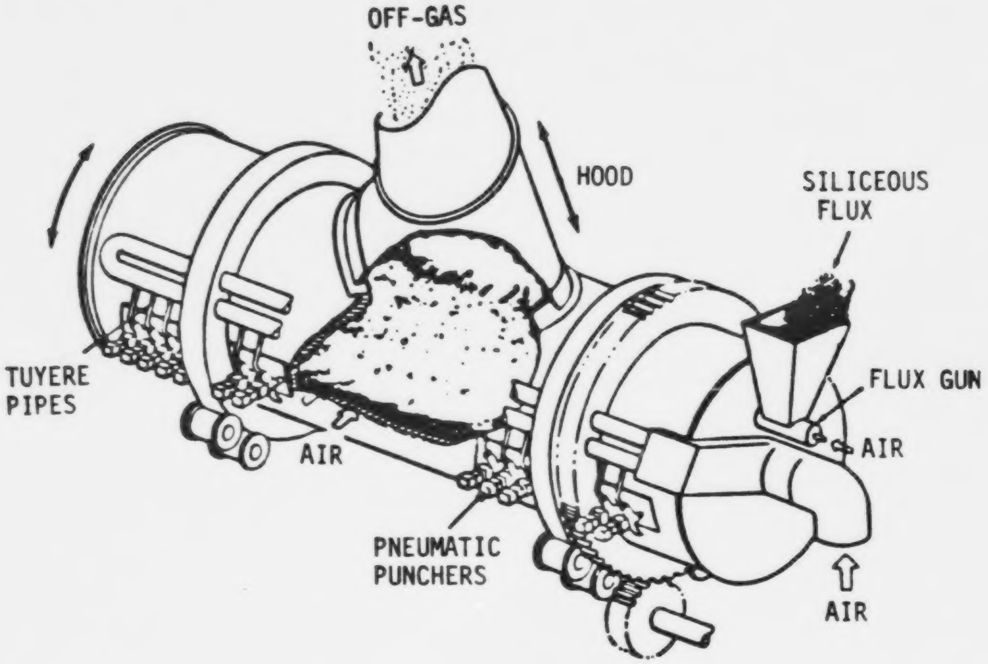
OFF-GAS
HOOD
SILICEOUS FLUX
FLUX GUN
AIR
TUYERE PIPES
AIR
PNEUMATIC PUNCHERS
AIR

Figure 4. Peirce-Smith converter.[15]

The base case for modification is the wet-feed reverberatory smelter. In the United States, wet-feed smelters are used at Magma, McGill, Ajo, and Morenci (Table 4). At Morenci, up to 35 percent of the concentrates are treated in a fluid-bed roaster; this calcine is fed to two of the five reverberatory furnaces, and the remaining 65 percent of the concentrate (as wet-feed) is sent to any one of the other three reverberatory furnaces. If oxygen-fuel smelting is utilized at these plants, wet-feed will still be used. The Morenci and Ajo smelters (Phelps Dodge) are under consent decrees either to convert to oxy-fuel or oxygen sprinkle smelting or to control SO_2 emissions to the atmosphere.

TABLE 4. SUMMARY OF EXISTING CONVENTIONAL WET-FEED REVERBERATORY FURNACES AND THEIR RELATED PROCESS EQUIPMENT AND SO_2 EMISSIONS AND REMOVAL

	Reverb(s) (size)	% S emitted[a]	Converters and their sizes	% S emitted[a] (removal)	Acid plant (capacity)
McGill	2 (31 x 132 ft, 32 x 132 ft)	31-32[b]	4 (2 at 12 x 30 ft, 1 at 13 x 30 ft, 1 at 15 x 35 ft)	41.56[b]	None
Ajo	1 (30 x 100 ft)	33.5[c]	3	59.1[c] 55.6[d]	98% S.C.[c] 2500 ppm tailgas[d] 239 TPD[d]
Magma	3 (32 x 102 ft, 34 x 102 ft, 36 x 102 ft)	27.1[e]	6 (3 at 13 x 32 ft 6 in., 3 at 15 x 32 ft)	67.9[e] 47.8[d]	2480 tons/day 5.5% S.C.[e] 2600 ppm[d] 837 TPD[d]
Morenci	3 (25 ft 6 in. x 102 ft 6 in., 25 ft 6 in. x 102 ft 6 in.,[g] 36 ft x 115 ft 4 in.)	28[f]	9 (13 x 30 ft)	51.1[f] 52.6[d]	1-2500 tons/day[f] 5+% 2000 ppm[f] 1-750 tons/day[f] 8% 4510 ppm[f] 743 TPD[d]

[a] Percent sulfur in feed to that operation which is emitted.

[b] Reference 16.

[c] Reference 17.

[d] Reference 18.

[e] Reference 19.

[f] Reference 20

[g] Calcine feed is sent to these furnaces only. Sulfur removal at calciner is 17%, and 35% of the concentrate is calcined.

Conventional smelting of wet-feed concentrate in a reverberatory furnace with air can release 27.3 to 38.3 percent of the sulfur in the concentrate as sulfur dioxide with a strength of approximately 1 percent SO_2 by volume. In the reverberatory furnace, flux materials (approximately 8 to 10 percent SiO_2) in the concentrate and flux additions combine with a portion of the iron to form an iron-silicate slag that also ties up some of the other minor elements in the charged concentrate. This type of smelting can produce a matte containing 25 to 41 percent copper, 30 to 43 percent iron, and 25 to 26 percent sulfur.[21]

The wet-feed process is one of the most endothermic processes in primary copper smelters that produce blister copper. Heat requirements in the form of gas, oil, or coal depend on the following:

- Amount of moisture to be evaporated from the furnace charge of wet concentrates and flux.
- Amount of iron and sulfur to be removed.
- Copper percentage desired in the matte.
- Amount of oxygen enrichment. (Oxygen enrichment helps to decrease the volume of discharged gases and decreases the resultant heat loss in the off-gas. It also increases throughput of concentrates to matte.)
- Temperature of the matte, slag, and exiting gases.
- Heat losses by convection, conduction, or radiation from the furnace proper due to type of refractory, air infiltration through unsealed openings, throughput, and the condition or maintenance of the furnace and enclosures.
- Amount of slag, reverts, etc. being recycled.
- Type of fuel used.

INCO FLASH FURNACE SMELTING

The use of 95 percent pure oxygen in the INCO flash smelting furnace permits the elimination of fuel for conversion of the copper ore concentrate to a matte. The process in this furnace is autogenous, and the heat required for smelting is produced by the reaction of oxygen with the iron sulfide in the concentrate and sulfur released to form iron oxides (Fe_xO_y) and SO_2, respectively. Table 5 presents the advantages of the INCO flash smelting furnace in contrast with the wet-feed reverberatory furnace requiring supplemental energy.

TABLE 5. ENERGY COMPARISON OF INCO FLASH SMELTING AND WET-FEED REVERBERATORY PROCESS THROUGH CATHODE COPPER

Item, based on same tonnage of blister copper	INCO flash smelting	Wet-feed reverberatory furnace
Matte grade, percent copper	45-55	35±
Volume percent SO_2 in the off-gas stream	77-80	1±
Gas volume handled, m^3/min (scfm)	99 (3500±)	2,830 (100,000±)
Hearth area, Mg (tons) concentrate/m^2 (ft^2)/day	13 (1.33)	2-3 (0.2-0.31)
Energy requirements per kg (ton) of cathode copper (including steam credits), J (Btu)	20.3 (17.49) x 10^6	32.2 (27.72) x 10^6
Steam credits in the above energy estimate, J (Btu)	0	7.2 (6.27) x 10^6

This comparison reflects the savings in blowing time at the Peirce-Smith converters to change the matte to blister copper. The INCO matte contains approximately 45 percent less iron than the wet-feed reverberatory matte; thus, the blowing time required for slagging will be correspondingly less.[13]

Based on L.R. Verney's study of copper matte grades and the number of converters required to produce the same yearly tonnage of blister copper, one converter with a matte grade of 50 percent copper is equivalent to 1.72 converters with a matte grade of 35 percent.[22] Thus, additional savings in manpower, energy, fluxing agents, material handling, and equipment usage (with its associated maintenance requirements) are also generated as a result of the increased copper in the matte.

Process Description

The INCO flash smelting furnace at INCO Metals, Copper Cliff Smelter, Sudbury, Ontario, Canada, is approximately 24.4 by 7.3 meters (80 ft long by 24 ft wide);[23] it can handle 1370 Mg (1500 tons) per day of concentrate and has operated at 1630 Mg (1800 tons) per day. Figure 5 shows the general arrangement of the INCO flash smelting process.[24] Incoming concentrate (8 to 10 percent moisture) is blended with a fluxing agent, such as silicate, and this mix is continuously fed to the top of the fluid bed dryer through a rotary sealing feeder. The solid particles are suspended in an upward flowing stream of hot combustion gas, and moisture is reduced to 0.1 to 0.2 percent. The dried concentrate feed and silica and the moist gases are discharged through

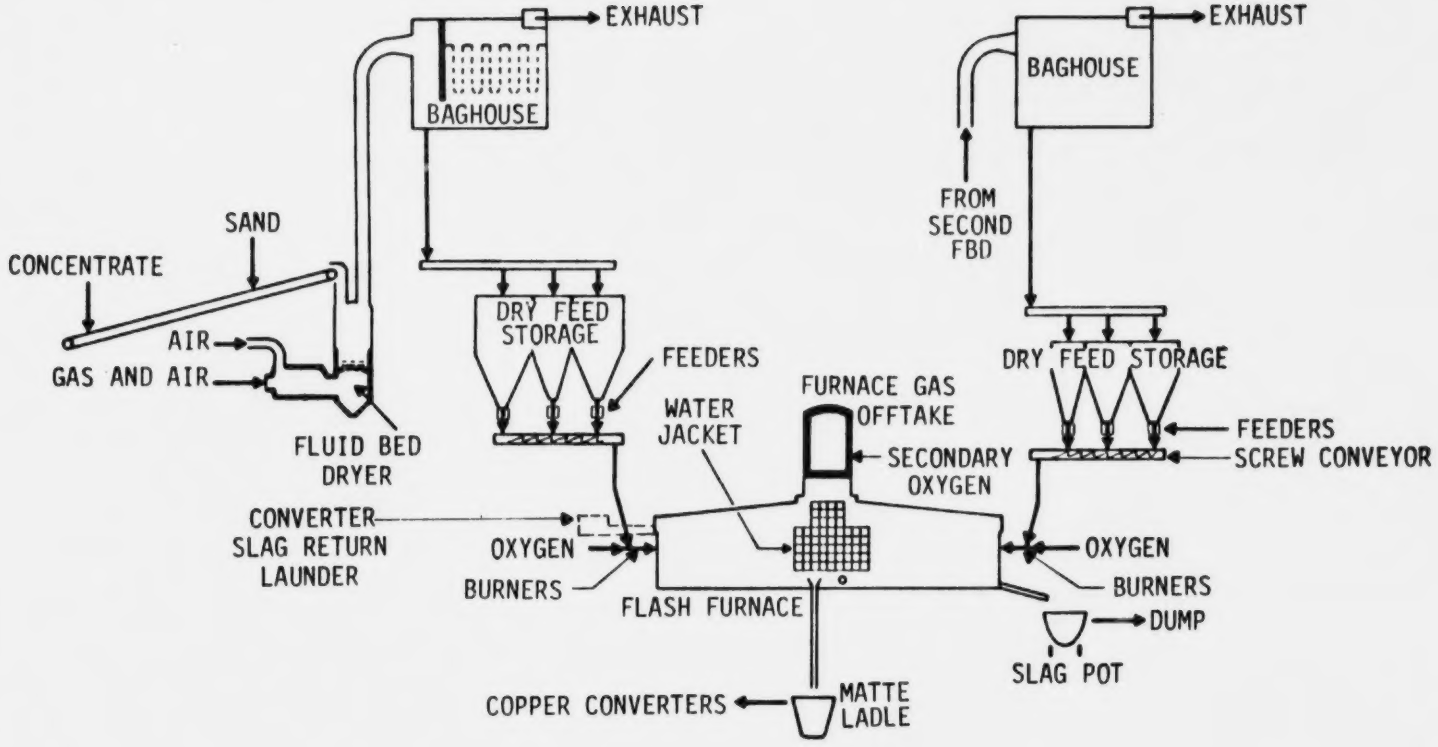
EXHAUST
BAGHOUSE
EXHAUST
BAGHOUSE
FROM
SECOND
FBD
SAND
CONCENTRATE
AIR
GAS AND AIR
FLUID BED
DRYER
DRY FEED
STORAGE
FEEDERS
DRY FEED STORAGE
FEEDERS
SCREW CONVEYOR
FURNACE GAS
OFFTAKE
SECONDARY
OXYGEN
WATER
JACKET
CONVERTER
SLAG RETURN
LAUNDER
OXYGEN
BURNERS
FLASH FURNACE
OXYGEN
BURNERS
DUMP
SLAG POT
COPPER CONVERTERS
MATTE
LADLE

Figure 5. INCO flash furnace general arrangement.[24]

the dryer roof for separation in the product fabric filter.[24] Normal operating conditions at INCO's plant are:

- Wind box temperature of 315°C (600°F)
- Bed temperature of 120°C (250°F)
- Off-gas volume with moisture at 105°C (220°F)

The collected and dried feed at the fabric filter is delivered to storage bins above the INCO furnace. The dried feed is delivered from the bins by constant-weight feeders to a screw conveyor, discharged from the conveyor, and gravity-fed through four feed tubes. The oxygen flash furnace is fired from both ends by four burners, two at each end.[24] The two burners on one end oppose the burners on the other end. As the dried feed is about to enter the furnace, it is met by a stream of oxygen and swept into the furnace area proper via the burners on the end walls. As the feed enters the furnace, an exothermic reaction of the oxygen with sulfur and iron occurs in the mix; within 1 m (3 ft) of entry, the oxygen reaction is nearly completed.[25] (See Figure 6). The flow of off-gases leaving the furnace through the central uptake is less than 5 percent of the wet-feed reverb flow from the reverberatory furnace. The SO_2 strength in the INCO furnace off-gas stream is approximately 80 percent by volume. The remainder of the gases in the offtakes consists of argon (95% pure oxygen process), nitrogen, carbon dioxide (combustion of flotation reagents in the concentrate), and air inleakage at the burners and the converter slag return. The furnace requires about half the floor area of the conventional reverberatory furnace; the ducting [approximately 0.76-m (2.5-ft) i.d.] with its associated dust control equipment (Figure 7) is also considerably smaller than the wet-feed reverberatory furnace. The copper content of the INCO furnace slag is only 0.6 to 0.7 percent and can be discarded.[14] The copper content of the converter slag depends on the FeO/SiO_2 ratio and ranges from 2 to 3 percent.[21] The furnace has a turndown* capability of approximately 3 to 1.[25] Including the converter (SO_2 off-gases at 4 percent by volume) and anode refining, the INCO without emission controls uses approximately 57.5 percent of the energy used by the conventional wet-feed reverberatory furnace without emission controls; the INCO with emission control requires 75.3 percent of the amount of energy required by the wet-feed reverberatory furnace without emission controls (see Table 2).

A material balance for the INCO oxygen flash furnace is shown in Table 6.[23] The daily input is 1750 Mg (1929 tons) of concentrate, recycled dust, and converter slag. The oxygen input is 0.2 kg/kg (0.2 lb/lb) of concentrate. The copper in the matte product is 55.2 percent, and the sulfur reduction is 56.9 percent with an off-gas of 81 percent SO_2 by volume.[23]

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* Turndown is the ability to operate at lower throughput rates.

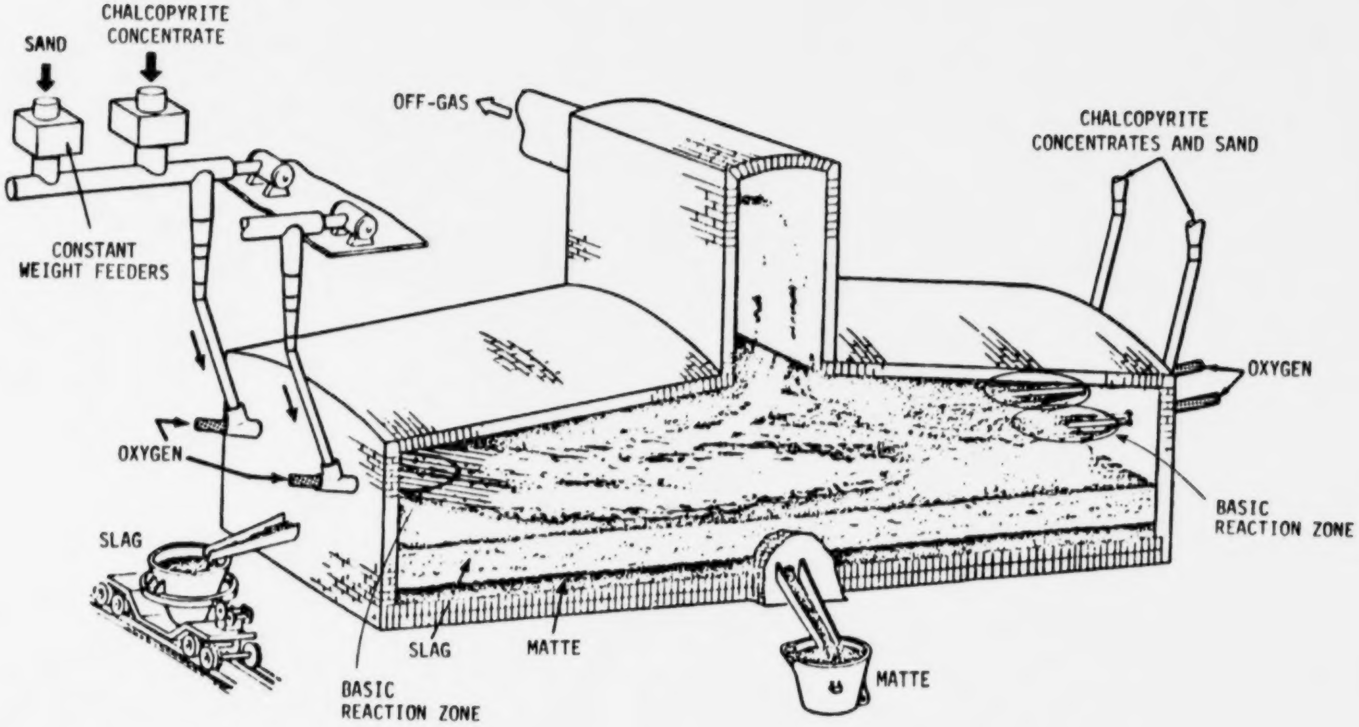
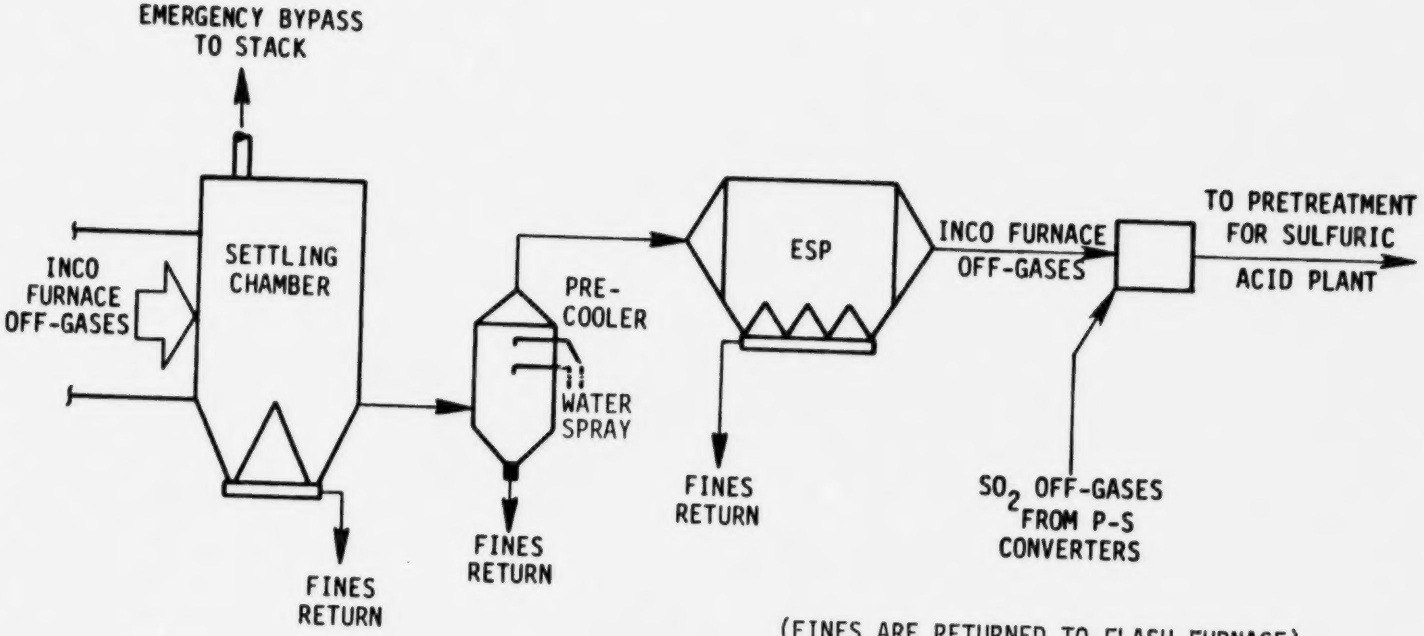

SAND
CHALCOPYRITE CONCENTRATE
CONSTANT WEIGHT FEEDERS
OFF-GAS
CHALCOPYRITE CONCENTRATES AND SAND
OXYGEN
OXYGEN
SLAG
BASIC REACTION ZONE
SLAG
MATTE
MATTE
BASIC REACTION ZONE

Figure 6. INCO flash furnace longitudinal cross section.[24]


EMERGENCY BYPASS TO STACK
INCO FURNACE OFF-GASES
SETTLING CHAMBER
FINES RETURN
PRE-COOLER
WATER SPRAY
FINES RETURN
ESP
FINES RETURN
INCO FURNACE OFF-GASES
SO2 OFF-GASES FROM P-S CONVERTERS
TO PRETREATMENT FOR SULFURIC ACID PLANT

(FINES ARE RETURNED TO FLASH FURNACE)

Figure 7. Flash furnace gas cleaning system with acid plant in lieu of a liquid SO_2 plant.

TABLE 6. INCO OXYGEN FLASH FURNACE MASS BALANCE FOR OPERATION WITH BRITISH COLUMBIA CONCENTRATE AND 100 PERCENT MOLTEN CONVERTER SLAG RECYCLE[23]

	Mg/day (tons/day)		Composition, wt. %				
Inputs	Rate, dry	Cu	Cu	Fe	S	SiO_2	Other
Concentrate	1360 (1499)	408 (449.7)	30.0	24.0	30.0	12.0	4.0
Recycled dust	68 (75)	23.3 (25.6)	34.2	23.1	10.8	12.4	19.5
Converter slag	322 (355)	16.1 (17.7)	5.0	47.3	1.5	26.4	19.8
Oxygen (95% purity)	274 (302)	-	-	-	-	-	-
Outputs							
Matte	765 (843)	422.3 (465.5)	55.2	20.0	23.7	-	1.1
Slag	757 (834)	6.0 (6.6)	0.79	43.2	1.5	32.9	21.6
Dust	56 (62)	19.3 (21.3)	34.5	27.4	8.5	13.7	15.9
Total off-gas (81% SO_2 by vol.)	493 (543)	-	-	-	45.3	-	-

For comparison, a material balance is shown in Table 7 for a conventional wet-feed reverberatory furnace with an input of 1826 Mg (2013 tons) per day of concentrate, flux materials, and converter slag. The copper in the matte is 31.8 percent, and the sulfur reduction is 31.3 percent (at a strength of 1 percent SO_2 in the off-gas).[8]

As the copper content in the matte increases and the iron content decreases, the blowing time required for slagging in the converter is reduced. With a 30 to 48 percent copper matte, two operating converters are required for a 90,720 Mg (100,000 ton) per year smelter,[22] whereas with a 50 percent copper matte, theoretically one 4-meter diameter by 9-meter (13-ft by 30-ft)[22] converter is sufficient. In each case, there would be a standby converter.

Retrofitting

Retrofitting an existing smelter's conventional reverberatory furnace with INCO oxygen-flash smelting requires the following major process equipment modifications:

- Installation of a fluid-bed dryer(s).
- Location of an oxygen plant in the approximate vicinity of the reverberatory furnace area.
- Location of gas cleaning equipment for a new acid plant, or, if an acid plant exists, modifications for the higher strength gases would involve adding a final absorption tower, additional heat exchangers, pumps, blower modification, tanks, and all necessary appurtenances (including additional catalyst, foundations, piping, structural steel, instrumentation, electrical equipment, insulation, painting, ducting modifications, enlarged storage facilities, and handling).
- Removal of an existing reverberatory furnace with its waste heat boilers and large ducting for installation of the INCO furnace with smaller ducting and gas-cleaning facilities, feed system, and oxygen injection.
- Control and instrument installation and modifications.
- Processing changes to the Peirce-Smith converters because the higher copper content requires less slag blowing time (i.e., less slag blowing time due to the decrease of iron in the matte, and less slag generated handling for returning to the INCO furnace).

Retraining of personnel also is required for the new process equipment and techniques.

TABLE 7. BUREAU OF MINES MASS BALANCE FOR CONVENTIONAL COPPER SMELTER REVERBERATORY FURNACE[8]

Inputs	Mg/day (tons/day)		Composition, wt. %				
	Rate, dry	Cu	Cu	Fe	S	SiO_2	Other
Concentrate	1036.8 (1142.9)	279.9 (308.6)	27	27	33.5	9	3.5
Lime rock	84.6 (93.3)	-	-	-	-	1.5	98.5
Quartzite	30.8 (33.9)	-	-	-	-	92.9	7.1
Converter slag	674.0 (743)	17.5 (19.3)	2.6	50.3	1.0	24.1	22.0
O_2 in air	120 (132.2)	-	-	-	-	-	-
Outputs							
Matte	919.9 (1014)	292.5 (322.5)	31.8	36.6	25.0	-	6.6
Slag	759.2 (836.9)	4.2 (4.6)	0.55	37.2	1.1	37.7	23.5
Fugitive emissions							
Dust	1.2 (1.3)	0.5 (0.5)	38.5	38.5	23.0	-	
SO_2	9.8 (10.8)	-	-	-	100	-	
Off-gas (1% SO_2 by vol.)	222.1 (244.8)	-			1.1		

The economics of converting a reverberatory furnace to an INCO flash furnace process system must show potential benefits in the annual operating costs resulting from the conversion (i.e., the payback must be realized within a reasonable time as influenced by interest rates, energy costs, acid usage, and the operating personnel required).

The cost of converting an existing reverberatory furnace to an INCO flash furnace mode will vary greatly depending on many site-specific factors. These include:

- Size, number, and condition of existing furnaces (i.e., if the hearth and refractory are in good condition, the value of hearth and refractory may be charged to the conversion cost) and the immediate physical areas (i.e., height, strength, and alteration capabilities of the existing building structure). Also, if furnaces can be replaced on a one-on-one basis without seriously disrupting production and operation.
- Type and composition of combined feeds (i.e., concentrate, reverts, slag, etc.).
- Plant configuration and available space if necessary to install a new building for the furnace and backup equipment with accessibility to existing converters and utilities.
- Availability, layout, and size of the existing sulfuric acid plant at the site, or space for the installation of new acid and oxygen plants.
- Disposal of sulfuric acid.

Cost Estimate

Capital and annual operating cost estimates are presented for converting conventional reverberatory furnaces sized to produce 90,720, 181,440, and 362,880 Mg (100,000, 200,000, and 400,000 tons)/year of blister copper (Tables 8 through 12). The concentrate contains approximately 31 percent sulfur, 29.5 percent copper, and 29 percent iron. Capital and operating costs are divided into major components so that they can be modified for a specific site.

Tables 9 through 12 present the total installed capital costs and annual operating costs for the conversion to the INCO oxygen-flash furnace system. The costs shown represent estimated capital and annual operating costs that include a 222-Mg (245-ton) per day cryogenic type oxygen plant and a 1066-Mg (1175-ton) per day double-contact sulfuric acid plant handling a combined

TABLE 8. SUMMARY OF ECONOMIC EVALUATIONS FOR FLASH FURNACE

DESCRIPTIVE SEGMENT	
Facility description	
Plant location	United States.
Construction cost	General; not indexed for labor costs for a specific area.
Capacity rating	
Blister copper	90,720 to 363,000 Mg/yr (100,000 to 400,000 tons/yr), handling 326,000 to 1,306,000 Mg/yr (340,000 to 1,360,000 tons/yr) of copper concentrate.
Abstract of scope	
Plant basis	Retrofit of existing primary copper smelter reverberatory furnace(s). Removal of an existing reverberatory furance and installation of the INCO oxygen-flash smelting furnace without disrupting the overall plant's capacity during retrofit. Space available for installation of smaller ducting and cleaning equipment for gas handling of the new furnace. Available level space for the addition of a 95 percent pure oxygen plant and a new double-contact/double-absorption sulfuric acid plant. Blending of INCO gases (77 to 80% SO_2) with 4 percent SO_2 Peirce-Smith converter off-gas for a combined flow of ±9 percent SO_2 gas to the acid plant. A matte containing 50± percent copper. Reduction in number of Peirce-Smith converters required for operations (higher copper matte grade).
Performance specification	
Energy	75 percent of the required process fuel equivalent energy is required per ton of blister copper as compared with the conventional wet-charge reverberatory furnace. This energy comparison includes oxygen and acid plants for INCO and no controls for SO_2 from the conventional wet-charge reverberatory furnaces and its Peirce-Smith converters. Smelting in the INCO unit is autogenous. Also, for blister copper, the INCO requires only 65 percent of the required process fuel equivalent energy for a wet-charge reverb.

(continued)

TABLE 8 (continued)

DESCRIPTIVE SEGMENT (continued)	
Performance specification (continued)	
SO_2 emissions	95± percent of the captured SO_2 from the INCO flash furnace and the Peirce-Smith converters is sent to the acid plant; ±2 percent of total S input escapes as fugitives from the INCO furnace, Peirce-Smith converters, and liquid molten movement as SO_2, and the remainder of sulfur is in the discarded INCO flash-furnace slag and particulates.
Stage of development	
Operating	INCO at Sudbury, Ontario, has successfully used oxygen flash smelting on copper and nickel ores for over 30 years. Also, an INCO smelting type unit is in operation at Almalyk, U.S.S.R. Two primary smelters in the United States are converting to INCO-type units for operation.
COST EVALUATION SEGMENT	
Specified parameters	
Interest rate	Interest for the capital cost is shown for the first year at 10 percent.
Facility life and depreciation period	9.5 years for oxygen and acid plants (range 7.5 to 11.5 years) and INCO flash smelting furnace 14 years (range 11 to 17 years) [from DEPRECIATION, IRS Publication 534, rev. November 1982].
Construction time	2 years
Reference units for process costs	Weight of blister copper, kg (lb)
Reference time for costs	January 1983
Cost index	Chemical Engineering (CE)
Inflation or projected costs - future	1.08^x (where x = years from January 1983 CE Index) [Equation is based on slope of CE Index for last 5 years.]

(continued)

TABLE 8 (continued)

COST EVALUATION SEGMENT (continued)	
Cost estimate - capital estimate (continued)	
Types of capital investment estimates	PEI cost files - vendor quotes, estimated fabrication costs/installation, and Bureau of Mines cost studies.
Allowance for funds during construction	The equivalent of 10.5 percent for 1 year based on on a 2-year construction period on borrowed money at 10 percent, payout 10 percent first 6 months, 35 percent at the end of 12 months, 75 percent at the end of 18 months, and 100 at the end of 24 months; 10 percent retained on major items until shakedown of equipment is completed at the end of 24-month period.
Cost Estimate - operating expense	Total operating expenses consist of utilities, operating and maintenance labor, supervision, overhead, supplies, maintenance materials, administration, taxes, insurance, depreciation, and cost of capital, but does not include the cost of fluxes or concentrate.
Time on stream	350 days/yr, approximately 8400 h/yr
Labor (operating)	$10.00/h, average hourly rate for all operators
Depreciation	Straight-line
Revenue	$22/Mg ($20/ton) sulfuric acid
Income tax rate	N.A.
Contingency	25 percent for process equipment, installation, engineering, startup, contractor's fee, and offsite expenses (note: Turnkey installation of the oxygen plant includes a 10 percent contingency; the acid plant includes a 12.5 percent contingency.)

TABLE 9. ESTIMATED CAPITAL COST OF RETROFITTING A CONVENTIONAL REVERBERATORY FURNACE WITH AN INCO OXYGEN-FLASH SYSTEM

				Blister copper, Mg (tons)[a] per year		
		Factor	Item	90,720[b] (100,000)	181,440[c] (200,000)	362,880[d] (400,000)
1.	Equipment cost - F.O.B. job site					
	Fluid-bed dryers, blowers, fabric filters, ducting, dust-removal screw conveyors, burners, INCO flash furnace and ancillaries, ducting, drop-out chamber, spray cooling chamber, wet ESP(s), hooding for ladles and launders at furnace, etc.			$ 5,299,200	$10,668,500	19,156,300
2.	Installation	0.456	1	2,416,400	4,864,800	8,735,300
3.	Piping, insulation	0.084	1&2	648,100	1,304,800	2,342,900
4.	Electrical instrumentation	0.081	1&2	625,000	1,258,200	2,259,200
5.	Foundations, painting, misc. items	0.048	1&2	370,300	745,600	1,338,800
6.	Structural building alterations			134,300	252,400	370,500
7.	Site clearance - remove existing reverb, ductwork			537,300	1,174,000	1,810,700
8.	Turnkey oxygen plant (0.8 kg O_2/kg Cu)			9,877,600	18,771,400	37,542,800
9.	Turnkey acid plant [1066 Mg/day at 8.5% SO_2 for 90,720 Mg/yr copper]			35,450,000	55,020,000	108,200,000
10.	Misc. - battery limits for Items 8 and 9 facilities	0.009	8&9	407,900	664,100	1,311,700
11.	Equipment costs (installed)			$55,766,100	$94,723,800	$183,068,200

(continued)

TABLE 9 (continued)

	Factor	Item	Blister copper, Mg (tons)[a] per year		
			90,720[b] (100,000)	181,440[c] (200,000)	362,880[d] (400,000)
Indirect Costs					
12. Engineering	0.10	1-7, 10	1,043,900	2,093,200	3,732,500
13. Startup	0.035	1-7, 10	365,400	732,600	1,306,400
22. Contractor's fee and offsite expenses	0.05	1-7, 10, 13	540,200	1,083,300	1,931,600
23. Contingency	0.25	1-7, 10, 12, 13, 22	3,097,000	6,210,400	11,074,000
24. Interest during construction	0.105	11-13, 22,23	6,385,300	11,008,500	21,116,800
30. Total indirect costs			11,431,800	21,128,000	39,161,300
31. TOTAL PLANT COSTS			$67,197,900	$115,851,800	$222,229,500

[a] Ton = 2,000 pounds.

[b] One INCO type furnace.

[c] Two INCO type furnaces.

[d] Three INCO type furnaces [no U.S. facility has 362,800 Mg/yr (400,000 ton/yr) capability installed at this time].

TABLE 10. ANNUAL OPERATING COSTS OF CONVERTING A REVERBERATORY FURNACE PRODUCING 90,720 Mg (100,000 tons) OF BLISTER COPPER PER YEAR TO AN INCO OXYGEN-FLASH FURNACE[a]

Item	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					$ per Mg (ton) of copper	$1000/yr
51. Raw materials[b] - lime[c]	0.907 Mg (tons)	8,700 tons	40.00	0.096 (0.087)	3.84 (3.48)	348
56. Direct labor[d]	Hours	2,080 h/man	10.00	-	-	2,475
57. Supervision	15%	Direct labor	10.00	-	-	371
58. Maintenance labor	1.875%	Installed cost	-	-	-	1,260
59. Maintenance supervision	20%	Maintenance labor	-	-	-	252
60. Maintenance materials	2%	Installed cost	-	-	-	1,344
61. Operating supplies	20%	Plant maintenance	-	-	-	571
62. Payroll overhead	60%	Labor and supervision	-	-	-	2,615
63. Electricity	kWh	9.252×10^7	0.04	1019.8 (925.2)	40.8 (37.01)	3,701
64. Oil	3.785 liters (gal)	8.283×10^5 gal	1.00	34.6 (8.283)	9.13 (8.283)	828
65. Natural gas	28.3 m^3 (1000 ft^3)	12,000 M ft^3	2.50	0.003 (0.12)	0.33 (0.30)	30
66. Water - process	3785 liters (1000 gal)	7.42×10^4 M gal	0.34	3.1 (0.742)	0.28 (0.25)	25
67. Water - cooling	3785 liters (1000 gal)	3.13×10^4 M gal	0.06	1.306 (0.313)	0.022 (0.02)	2
71. Administration and overhead	40%	Labor, supervision, materials, and supplies				2,509
76. Taxes and insurance	2%	Installed cost				1,344
78. Depreciation (straight-line)						
Acid and oxygen plant	10.526%	Acid and oxygen plant costs				5,320
Smelting equipment	7.143%	Smelter costs				1,190
79. Cost of funds or interest	10.00%	Total plant cost				6,720
80. Total operating cost[b,e]						30,905
82. Byproduct credit[f] - H_2SO_4	0.907 Mg (tons)	297,000 tons	20.00	3.27 (2.97)	65.4 (59.40)	-5,940
90. Adjusted total operation costs with acid credit						24,965
100. Cost per kilogram (pound) of blister copper with acid credit						0.2752 (0.1248)
101. Cost per kilogram (pound) of blister copper with steam credit but no acid credit						0.3407 (0.1545)
102. Cost per kilogram (pound) of blister copper with steam credit and acid neutralization						0.4145 (0.1880)

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[a] Includes acid plant, oxygen plant, reduced blowing time at Peirce-Smith converters, material handling, gas handling, and standby natural gas for preheating.

[b] Cost of ore or fluxes, land, or sludge disposal not included.

[c] Neutralization of acid plant sludge.

[d] 119 people.

[e] Does not include depreciation and maintenance for Peirce-Smith converters and ancillaries or material handling.

[f] Either for sale (F.O.B. the smelter) or credited if utilized within the company or corporation.

TABLE 11. ANNUAL OPERATING COSTS OF CONVERTING A REVERBERATORY FURNACE PRODUCING 181,400 Mg (200,000 tons) OF BLISTER COPPER PER YEAR TO AN INCO OXYGEN-FLASH FURNACE[a]

Item	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					$ per Mg (ton) of copper	$1000/yr
51. Raw materials[b] - lime[c]	0.907 Mg (tons)	17,400 tons	40.00	0.096 (0.087)	3.84 (3.48)	696
56. Direct labor	Hours	2,080 h/man	10.00	-	-	2,715
57. Supervision	15%	Direct labor	10.00	-	-	407
58. Maintenance labor	1.875%	Installed cost	-	-	-	2,172
59. Maintenance supervision	20%	Maintenance labor	-	-	-	434
60. Maintenance materials	2%	Installed cost	-	-	-	2,317
61. Operating supplies	20%	Plant maintenance	-	-	-	985
62. Payroll overhead	60%	Labor and supervision	-	-	-	3,437
63. Electricity	kWh	1.8504×10^8	0.04	1019.8 (925.2)	40.8 (37.01)	7,402
64. Oil	3.785 liters (gal)	16.566×10^5 gal	1.00	34.6 (8.283)	9.13 (8.283)	1,657
65. Natural gas	28.3 m^3 (1000 ft^3)	24,000 M ft^3	2.50	0.003 (0.12)	0.33 (0.30)	60
66. Water - process	3785 liters (1000 gal)	1.484×10^5 M gal	0.34	3.1 (0.742)	0.28 (0.25)	50
67. Water - cooling	3785 liters (1000 gal)	6.26×10^4 M gal	0.06	1.306 (0.313)	0.021 (0.02)	4
71. Administration and overhead	40%	Labor, supervision, materials, and supplies				3,612
76. Taxes and insurance	2%	Installed cost				2,317
78. Depreciation (straight-line)						
Acid and oxygen plant	10.526%	Acid and oxygen plant costs				8,660
Smelting equipment	7.143%	Smelter costs				2,399
79. Cost of funds or interest	10.00%	Total plant cost				11,585
80. Total operating cost[b,d]						50,909
82. Byproduct credit[e] - H_2SO_4	0.907 Mg (tons)	594,000 tons	20.00	2.17 (2.97)	65.4 (59.40)	-11,880
90. Adjusted total operating costs with acid credit						39,029
100. Cost per kilogram (pound) of blister copper with acid credit						0.2151 (0.0976)
101. Cost per kilogram (pound) of blister copper with no acid credit						0.2806 (0.1273)
102. Cost per kilogram (pound) of blister copper with acid neutralization						0.3545 (0.1608)

[a] Includes acid plant, oxygen plant, reduced blowing time at Peirce-Smith converters, material handling, gas handling, and standby natural gas for preheating.

[b] Cost of ore or fluxes, land, or sludge disposal not included.

[c] Neutralization of acid plant sludge.

[d] Does not include depreciation and maintenance for Peirce-Smith converters and ancillaries or material handling.

[e] Either for sale (F.O.B. the smelter) or credited if utilized within the company or corporation.

TABLE 12. ANNUAL OPERATING COSTS OF CONVERTING A REVERBERATORY FURNACE PRODUCING 362,880 Mg (400,000 tons) OF BLISTER COPPER PER YEAR TO AN INCO OXYGEN-FLASH FURNACE[a]

Item	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					$ per Mg (ton) of copper	$1000/yr
51. Raw materials[b] - lime[c]	0.907 Mg (tons)	34,800 tons	40.00	0.096 (0.087)	3.84 (3.48)	1,392
56. Direct labor	Hours	2,080 h/man	10.00	-	-	4,368
57. Supervision	15%	Direct labor	10.00	-	-	655
58. Maintenance labor	1.875%	Installed cost	-	-	-	4,167
59. Maintenance supervision	20%	Maintenance labor	-	-	-	833
60. Maintenance materials	2%	Installed cost	-	-	-	4,445
61. Operating supplies	20%	Plant maintenance	-	-	-	1,889
62. Payroll overhead	60%	Labor and supervision	-	-	-	6,014
63. Electricity	kWh	3.701×10^8	0.04	1019.8 (925.2)	40.8 (37.01)	14,803
64. Oil	3.785 liters (gal)	33.132×10^5gal	1.00	34.6 (8.283)	9.13 (8.283)	3,313
65. Natural gas	28.3 m^3 (1000 ft^3)	48,000 M ft^3	2.50	0.003 (0.12)	0.33 (0.30)	120
66. Water - process	3785 liters (1000 gal)	2.968×10^5 M gal	0.34	3.1 (0.742)	0.28 (0.25)	100
67. Water - cooling	3785 liters (1000 gal)	1.252×10^5 M gal	0.06	1.306 (0.313)	0.021 (0.02)	8
71. Administration and overhead	40%	Labor, supervision, materials, and supplies				6,543
76. Taxes and insurance	2%	Installed cost				4,445
78. Depreciation (straight-line)						
Acid and oxygen plant	10.526%	Acid and oxygen plant costs				17,104
Smelting equipment	7.143%	Smelter costs				4,267
79. Cost of funds or interest	10.00%	Total plant cost				22,223
80. Total operating cost[b,d]						96,689
82. Byproduct credit[e] - H_2SO_4	0.907 Mg (tons)	1.19×10^6 tons	20.00	3.27 (2.97)	65.4 (59.40)	-23,760
90. Adjusted total operating costs with acid credit						72,929
100. Cost per kilogram (pound) of blister copper with acid credit						0.2010 (0.0912)
101. Cost per kilogram (pound) of blister copper with no acid credit						0.2664 (0.1209)
102. Cost per kilogram (pound) of blister copper with acid neutralization						0.3403 (0.1544)

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[a] Includes acid plant, oxygen plant, reduced blowing time at Peirce-Smith converters, material handling, gas handling, and standby natural gas for preheating.

[b] Cost of ore or fluxes, land, or sludge disposal not included.

[c] Neutralization of acid plant sludge.

[d] Does not include depreciation and maintenance for Peirce-Smith converters and ancillaries or material handling.

[e] Either for sale (F.O.B. the smelter) or credited if utilized within the company or corporation.

stream of 80 percent SO_2 from the INCO oxygen-flash furnace and a 4 percent SO_2 stream from the Peirce-Smith converters. All the costs are in January 1983 dollars (Chemical Engineering Plant Cost Index 315.5). These costs are based on vendor data, previous in-house estimates, and Bureau of Mines information. The costs include fixed charges for depreciation, cost of capital and interest during construction, equipment startup, and spares. The oxygen plant is sized without the use of recycled fines and slag in the furnace. Based on material balance, the difference in oxygen requirements without reverts (fines and slag) is 2 percent higher than they would be if 14 percent reverts (fines, slag) were utilized.[22] The oxygen plant is based on 95 percent purity, 95 percent O_2 utilization, and 1 percent excess for other plant usage. The minimum sulfuric acid plant required is 813 Mg (896 tons) per day; however, a 1066-Mg (1175-ton) unit was selected to allow for short overlapping of two Peirce-Smith converters. As shown in Table 9, the oxygen plant and sulfuric acid plant systems are the major cost items and account for the largest percentage of the total capital costs.

Total annualized smelting costs for 90,720 Mg (100,000 tons) of blister copper can vary from \$0.275 to \$0.341/kg (\$0.125 to \$0.154/lb) of copper with no credit for the sale of sulfuric acid. The major annualized costs are the costs of capital and depreciation. Annualized costs for the 90,720-Mg (100,000-ton) unit can be reduced by approximately 20 percent if a market exists for the sulfuric acid at \$20.00/ton F.O.B. for the smelter.

OXYGEN SPRINKLE SMELTING

Another technique for modifying a primary copper smelter to decrease energy consumption and to increase SO_2 off-gas concentration is oxygen-sprinkle smelting, as proposed by Queneau and Schuhmann.[11] This technique was partially tested at the Phelps-Dodge smelter in Morenci in conjunction with the Dravo Corporation; however, approximately two-thirds to three-fourths of the feed was oxygen sprinkle smelted and one-fourth to one-third was fed to the furnace from the reverberatory roof at its sidewalls to act as a heat shield and, in essence, was smelted to a degree as in a standard reverberatory furnace. Therefore, the Morenci test unit was only a modified oxygen sprinkle smelting technique.

Process Description

The oxygen sprinkle smelting technique by Queneau and Schuhmann,[11] which utilizes a conventional reverberatory furnace approximately 10 meters wide by 31 meters long (32 ft x 102 ft), would probably be capable of smelting 1225 Mg (1350 tons) of concentrate per day based on a matte grade of 50 percent copper. Figure 8 presents a pictorial representation of a reverberatory furnace converted to oxygen-sprinkle smelting. The schematic in Figure 9 shows the flow in the oxygen-sprinkle smelting process.

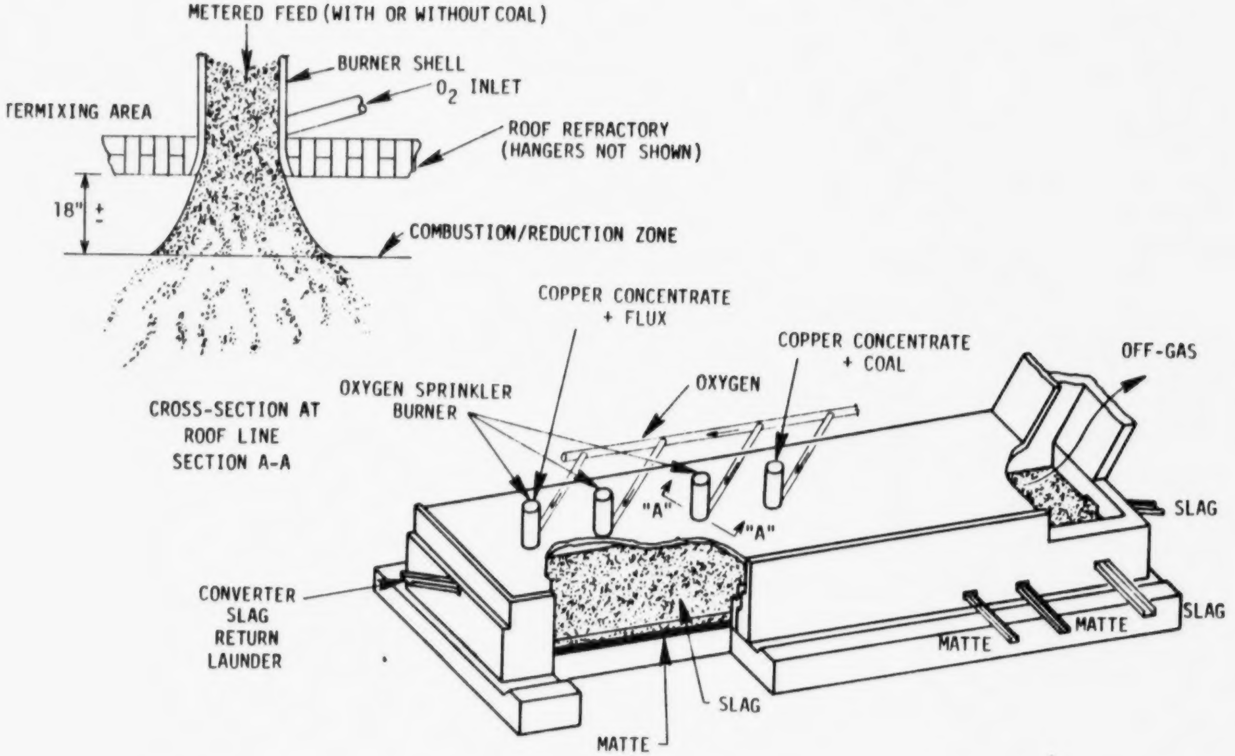
METERED FEED (WITH OR WITHOUT COAL)
BURNER SHELL
O_2 INLET
TERMIXING AREA
ROOF REFRACTORY (HANGERS NOT SHOWN)
18" ±
COMBUSTION/REDUCTION ZONE
CROSS-SECTION AT ROOF LINE SECTION A-A
COPPER CONCENTRATE + FLUX
COPPER CONCENTRATE + COAL
OXYGEN SPRINKLER BURNER
OXYGEN
OFF-GAS
"A"
"A"
SLAG
CONVERTER SLAG RETURN LAUNDER
SLAG
MATTE
MATTE
MATTE
SLAG
MATTE

Figure 8. Oxygen sprinkle smelter.[11]

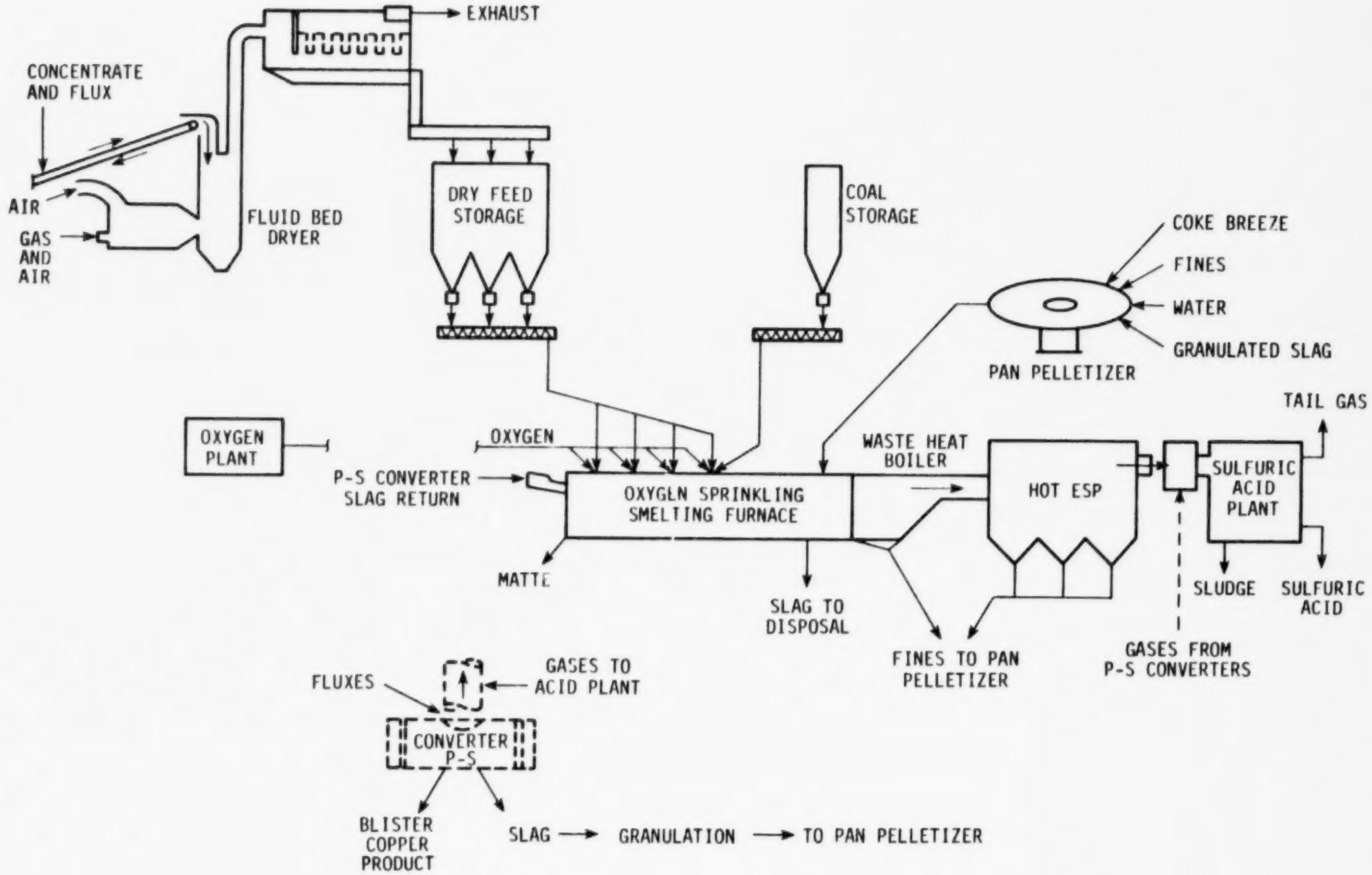
CONCENTRATE AND FLUX
AIR
GAS AND AIR
FLUID BED DRYER
EXHAUST
DRY FEED STORAGE
COAL STORAGE
COKE BREEZE
FINES
WATER
GRANULATED SLAG
PAN PELLETIZER
OXYGEN PLANT
OXYGEN
P-S CONVERTER SLAG RETURN
OXYGEN SPRINKLING SMELTING FURNACE
WASTE HEAT BOILER
HOT ESP
SULFURIC ACID PLANT
TAIL GAS
SLUDGE
SULFURIC ACID
MATTE
SLAG TO DISPOSAL
FINES TO PAN PELLETIZER
GASES FROM P-S CONVERTERS
FLUXES
GASES TO ACID PLANT
CONVERTER P-S
BLISTER COPPER PRODUCT
SLAG
GRANULATION
TO PAN PELLETIZER

Figure 9. Oxygen sprinkle reverberatory furnace and ancillary equipment.

Similar to the INCO process, incoming concentrate and flux are dried in the fluid-bed dryer, collected in a fabric filter, and stored in bins above the modified reverberatory furnace. The dried feed (concentrate and flux) is then delivered to the burners on top of the roof of the reverberatory furnace. Before the dried feed enters the furnace proper at the roof line, oxygen is introduced, which forces the dried feed into suspension and almost simultaneously combines with some of the sulfur to form SO_2 and iron oxide. This reaction occurs approximately 18 inches below the roof line. The last burner (see Figure 8) is located at the center of the modified reverberatory furnace on the longitudinal axis and will contain the feed plus about 3 percent by weight of coal with respect to the total feed weight input charged to the furnace.[11] The coal provides the required supplemental fuel. If the first two or three burners in the roof line use oxygen smelting of chalcopyrite concentrate and the last one uses oxygen flash smelting of cuproferrous pyrite concentrate and coal, the modified furnace would theoretically produce a 60 percent copper matte and an SO_2 with a strength of 35 percent.[26]

Matte and slag are tapped in the same manner as the conventional reverberatory furnace. Figures 8 and 9 show the process flow and the basic modifications to the existing reverberatory system that are required to convert to an oxygen sprinkle-smelting system. These are:

1) Installing a new or modified suspended type of roof for placement of the burners for feed, oxygen, and ease of servicing, and making the modified reverberatory furnace roof as tight as possible to minimize air infiltration and dilution of the off-gas SO_2 stream.

2) Installing additional tapping holes in the modified or rebuilt reverberatory furnace for increased matte and slag removal.

3) Making the furnace as tight as possible to minimize air infiltration into the furnace.

4) Modifying or replacing the existing feed mechanisms and/or storage bins with new units, and coordinating the metered feed and oxygen usage with the bins and material handling equipment.

5) Altering the furnace buckstays and building structure of existing and/or new storage bins and material handling equipment.

6) Installing an oxygen plant with oxygen lines and controls.

7) Upgrading the existing acid plant to handle higher SO_2 content in the gas stream and converting to double-absorption/double-contact (if currently a single-absorption/single-contact acid plant) or installing a new acid plant with gas handling and acid storage and shipping facilities.

8) Altering waste-heat boilers for reduced off-gas generation to approximately 30 percent of that required for a conventional reverberatory furnace, and minimizing air inleakage.

For good off-gas control, the ducting from the waste-heat boilers should be replaced with appropriate sized ducting. For the gas stream volume generated, particulate-removal control equipment should be added [i.e., hot ESP(s), spray cooling chamber, wet ESP(s), dropout chambers, etc.]. Provisions also should be made for coal handling and pulverizing, including storage and metered feeding to the burner. Based on an estimated carryover of fines of 5 to 6 percent of the feed compared with INCO's 2 percent, some agglomeration of the fines returning to the furnace may be beneficial to minimize the fines being carried over again and the losses by attrition.

The heat balances shown by Queneau and Schuhmann[11] for a matte with a 50 percent copper content indicate that a heat input of 200,000 kcal/Mg (720,000 Btu per ton) of concentrate is required. Furnace size can remain the same as for a conventional reverberatory furnace. Oxygen utilization is 0.2 to 0.22 kg per kg (0.2 to 0.22 pound per pound) of concentrate.[11]

Coal (3 percent by weight of the concentrate) is added to the last burner to achieve a thermally balanced operation for a 50 percent copper matte.[11] Thus, for 1361 Mg (1500 tons) per day of concentrate, coal is added at the rate of 40.8 Mg (45 tons or the equivalent of 2.72×10^8 kilcalories or 1.08×10^9 Btu) per day. This generates approximately 1.55 Mg (1.71 tons) per day of additional SO_2 and 3.3 Mg (3.6 tons) per day of ash in the slag (based on a coal containing 2 percent sulfur and 8 percent ash). The off-gas volume generated for equivalent SO_2 removal would be approximately three times greater than that from an INCO flash furnace. The INCO off-gas is 80 percent SO_2, whereas oxygen-sprinkle off-gas is 26 percent.[11]

The overall equivalent energy required for the modified oxygen-sprinkle smelter to produce blister copper without steam credit but including an acid plant is 1,118,600 kcal/Mg (4,027,000 Btu/ton) of concentrate when oxygen and coal are used.[10,11] This is 21 percent more than the energy requirement of an INCO furnace with acid plants, but it is only 83 percent of that required to produce blister copper in a wet-feed uncontrolled, conventional reverberatory furnace. This is without steam credit for the oxygen-sprinkle smelting system, but with steam credit for the wet-feed, uncontrolled conventional reverberatory furnace (see Table 2).

Turning down the oxygen sprinkle smelting furnace requires the use of additional energy to control the heat losses through the refractory and in the off-gases. Also, the oxygen-sprinkle furnace turndown ratio would be less than the INCO's 3 to 1 ratio because of its larger physical size and greater heat input.

Retrofitting

Retrofitting a smelter's conventional reverberatory furnace with an oxygen-sprinkle flash smelting system may require the following major process equipment modifications:

- Installation of fluid-bed or rotary dryer(s)
- Installation of an oxygen plant in the approximate vicinity of the reverberatory furnace area
- Installation of day bins and storage, pulverizing, weighing, and handling facilities for coal
- Modifications to and/or removal (with new installation) of material handling equipment for the feed to the furnace proper
- Installation of gas cleaning for the acid plant and storage and shipping facilities. If an acid plant exists, modifications to produce higher-strength gases could involve addition of a final absorption tower, additional heat exchangers, pumps, blower modifications, tanks, and additional catalyst; also, the appropiate modification or addition of foundations, piping, structural steel, instrumentation, electrical work, insulation, painting, ducting modifications, enlarged acid storage and handling facilities
- Alterations to the existing reverberatory furnace, including modified or new waste-heat boilers, ducting for new roof design and/or hangers and burners, modification to the feed system and weigh controls, tightening of the furnace openings, additional slag and matte launders, alterations to the uptake area, smaller ducting and gas cleaning facilities, additional fines handling equipment, oxygen piping to burners, structural changes to the building and buckstays, coal feeding, and all other necessary appurtenances
- Control and instrument installation and/or modifications

- Rescheduling operations of the Peirce-Smith converters for decreased blowing time

Retraining of personnel for the new process equipment and techniques will also be necessary.

Cost

The cost of converting a reverberatory furnace to an oxygen-enriched firing mode can vary greatly, depending on many site-specific factors. These include:

- Size and condition of existing furnaces and their immediate physical area and whether furnaces can be replaced on a one-on-one basis without seriously disrupting production and operation
- Type and composition of combined feeds
- Plant configuration and available space if necessary to install a new building for the furnace and backup equipment with accessibility to existing converters and utilities
- Availability and size of the sulfuric acid plant at the site, if one exists
- Disposal of sulfuric acid

Table 13 presents an economic evaluation and description of the conversion of a reverberatory furnace to oxygen-sprinkle smelting. Tables 14 through 17 show the estimated capital and annual operating costs of converting a reverberatory furnace(s) sized to produce 90,720, 181,440, and 362,880 Mg (100,000, 200,000, and 400,000 tons) per year of blister copper to oxygen-sprinkle smelting. The concentrate analysis is 31 percent sulfur, 29.5 percent copper, and 29 percent iron.

The capital and annual operating costs include a 222-Mg (245-ton) per day oxygen plant and a 1066-Mg (1175-ton) per day double-contact sulfuric acid plant for the 90,720-Mg (100,000-ton) smelter. The acid plant receives a combined 7.5 percent SO_2 stream generated by a 26 percent SO_2 stream from the oxygen-sprinkle furnace and a 4 percent SO_2 stream from the Peirce-Smith converters.[11] These costs are expressed in January 1983 dollars (Chemical Engineering Plant Cost Index of 315.5). These costs are based on vendor data, previous in-house estimates, and Bureau of Mines information. The costs include fixed charges for depreciation, cost of capital and interest during construction, equipment startup, and spares. The oxygen plant is based on 95 percent purity, 95 percent utilization, and 1 percent excess for

TABLE 13. SUMMARY OF ECONOMIC EVALUATIONS FOR OXYGEN-SPRINKLE SYSTEM[10]

DESCRIPTIVE SEGMENT	
Facility description	
Plant location	United States
Construction cost	General; not indexed for a specific area for labor costs
Capacity rating	
Blister copper	90,720 to 363,000 Mg/yr (100,000 to 400,000 tons/yr), handling 326,000 to 1,306,000 Mg/yr (±360,000 to 1,440,000 tons/yr) of copper concentrate, Cu ±29.5 percent.
Abstract of scope	
Plant basis	Retrofit of existing primary copper smelter reverberatory furnace(s). Removal of the existing furnace and installation of a modified reverberatory furnace and new waste-heat boilers for an oxygen-sprinkle flash smelting system without disrupting the overall plant's capacity during retrofit. Space available for installation of smaller ducting and cleaning equipment for gas handling of the new furnace. Available level space for the addition of a 95 percent pure oxygen plant and a new double contact-double absorption sulfuric acid plant. Blending of the modified reverberatory gases of 26 percent SO_2 with 4 percent Peirce-Smith converter SO_2 off-gas for a combined flow of 7.5 percent SO_2 gas to the acid plant. Copper in matte 50 percent. The number of operating Peirce-Smith converters is reduced because of the higher copper matte grade. Acid plant with rail and truck handling facilities and 5-day storage.
Performance specification	
Energy	21 percent reduction in energy per ton of blister copper compared with the conventional wet-charge reverberatory furnace. This energy comparison includes the oxygen and acid plant for oxygen sprinkle flash smelting and no controls for SO_2 for a conventional wet-charge reverberatory furnace and also credits the equivalent steam energy for both.

(continued)

TABLE 13 (continued)

Performance specification (continued)	
SO_2 emissions	94+ percent of captured SO_2 is sent to the acid plant; 3 percent of SO_2 escapes as fugitives, remainder of sulfur is in slag and particulate.
Stage of development	
Operating	None. Some experimental work by Phelps-Dodge at the Morenci smelter in conjunction with the Dravo Corporation. Modified oxygen-sprinkle technique at Morenci; not all concentrate to furnace was oxygen sprinkle smelted.
COST EVALUATION SEGMENT	
Specified parameters	
Interest rate	Interest for the capital cost is shown for the first year at 10 percent.
Facility life and depreciation period	9.5 years for oxygen and acid plants (range 7.5 to 11.5 years) and 14 years for the oxygen sprinkle flash smelting furnace (range 11 to 17 years) [from DEPRECIATION, IRS Publication 534, rev. November 1982].
Construction time	2 years
Reference units for process costs	Weight of blister copper, kg (lb)
Reference time for costs	January 1983
Cost index	Chemical Engineering (CE)
Inflation or projected costs - future	1.08^x (where x = years from January 1983 CE Plant Index). [Equation is based on slope of CE Plant Index for past 5 years.]
Cost estimate - capital estimate	
Types of capital investment estimates	PEI cost files - vendor quotes, estimated fabrication costs and installations, and Bureau of Mines cost studies

(continued)

TABLE 13 (continued)

Cost estimate - capital estimate (continued)	
Allowance for funds during construction	10.5 percent total for the 2 years on borrowed money at 10percent, payout 10 percent first 6 months, 35 percent at the end of 12 months, 75 percent at the end of 18 months, and 100 percent at the end of 24 months; 10 percent retained on major items until shakedown completed at the end of a 24-month period.
Cost Estimate - operating expense	Total operating expenses consist of utilities, operating and maintenance labor, supervision, overhead, supplies, maintenance materials, administration, taxes, insurance, depreciation, and cost of capital, but does not include the cost of fluxes or concentrate
Time on stream	350 days/yr, approximately 8400 h/yr
Labor (operating)	$10.00/h, average hourly rate for all operators
Depreciation	Straight-line
Revenue	$22/Mg ($20/ton) sulfuric acid
Income tax rate	N.A.
Contingency	25 percent for process equipment, installation, engineering, start-up, contractor's fee, and offsite expenses (Note: Turnkey installation of the oxygen plant includes a 10 percent contingency, and the acid plant indicates a 12.5 percent contingency.)

TABLE 14. ESTIMATED CAPITAL COST OF CONVERTING A REVERBERATORY FURNACE TO AN OXYGEN-SPRINKLE SYSTEM

	Factor	Item	Blister copper, Mg (tons)[a] per year		
			90,720[b] (100,000)	181,440[c] (200,000)	362,880[d] (400,000)
1. Equipment cost - F.O.B. job site					
Rotary dryers, ESP, dust removal screw conveyors, modified reverb furnace with waste heat boilers and ancillaries, ducting, hot ESP(s), hood for launders and ladles at furnace, etc.			$ 5,920,200	$11,918,700	$ 19,912,400
2. Installation	0.456	1	2,699,600	5,434,900	9,080,100
3. Piping, insulation	0.084	1&2	724,100	1,457,700	2,435,400
4. Electrical, instrumentation	0.081	1&2	698,200	1,405,600	2,348,400
5. Foundations, painting, misc.	0.048	1&2	413,800	572,100	1,391,600
6. Structural building alterations			134,300	252,400	488,600
7. Site clearance - remove existing reverb, ductwork			537,300	1,174,000	2,447,400
8. Turnkey - oxygen plant			9,877,600	18,771,400	37,542,800
9. Turnkey - acid plant [1066 Mg/day at 7.46 percent SO_2 for 90,720 Mg/year of copper]			40,300,000	61,700,000	119,400,000
10. Misc. - battery limits for Items 8 and 9	0.009	8&9	451,600	724,200	1,412,500
11. Equipment costs (installed)			61,756,700	103,411,000	196,459,200

(continued)

TABLE 14 (continued)

	Factor	Item	Blister copper, Mg (tons)[a] per year		
			90,720[b] (100,000)	181,440[c] (200,000)	362,880[d] (400,000)
Indirect Costs					
12. Engineering	0.10	1-7,10	1,157,900	2,366,400	3,951,600
13. Startup	0.035	1-7,10	405,300	828,200	1,383,100
22. Contractor's fee and offsite	0.05	1-7,10	579,000	1,183,200	1,975,800
23. Contingency	0.25	1-7, 10,12, 13,22	3,430,000	7,010,400	11,706,700
24. Interest during construction	0.105	11-13, 22,23	7,069,600	12,053,900	22,625,000
30. Total indirects			$12,642,100	$ 23,442,100	$ 41,642,200
31. TOTAL PLANT COSTS (INSTALLED)			$74,398,800	$126,853,100	$238,101,400

[a] Mg = 1000 kilograms; ton = 2000 pounds.

[b] One O-S type furnace.

[c] Two O-S type furnaces.

[d] Three O-S type furnaces, but no U.S. facility has 362,880 Mg/yr capability installed at the present.

TABLE 15. ANNUAL OPERATING COSTS OF CONVERTING A REVERBERATORY FURNACE PRODUCING 90,720 Mg (100,000 tons) OF BLISTER COPPER PER YEAR TO AN OXYGEN-SPRINKLE SYSTEM[a]

	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					$ per Mg (ton) of copper	$1000/yr
51. Raw materials[b] - lime[c]	0.907 Mg (tons)	8,700 tons	40.00	0.96 (0.087)	3.84 (3.48)	348
56. Direct labor (134 people)	Hours	2,080 h/man	10.00	-	-	2,787
57. Supervision	15%	Direct labor	10.00	-	-	418
58. Maintenance labor	1.875%	Installed cost	-	-	-	1,395
59. Maintenance supervision	20%	Maintenance labor	-	-	-	279
60. Maintenance materials	2%	Installed cost	-	-	-	1,488
61. Operating supplies	20%	Plant maintenance	-	-	-	632
62. Payroll overhead	60%	Labor and supervision	-	-	-	2,927
63. Electricity	kWh	9.571×10^7	0.04	1055 (957.1)	42.2 (38.28)	3,828
64. Coal and oil	0.907 Mg (tons) 3.785 liters (gal)	11,736 tons 8.283×10^5 gal	35.00 1.00	0.129 (0.117) 34.6 (8.28)	4.53 (4.11) 9.13 (8.28)	411 828
65. Natural gas	28.3 m³ (1000 ft³)	12,000 M ft³	2.50	0.003 (0.12)	0.33 (0.30)	30
66. Water - process	3785 liters (1000 gal)	6.77×10^4 M gal	0.34	2.82 (0.677)	0.27 (0.23)	23
67. Water - cooling	3785 liters (1000 gal)	3.32×10^4 M gal	0.06	1.386 (0.332)	0.022 (0.02)	2
71. Administration and overhead	40%	Labor, supervision, materials, and supplies	-	-	-	2,800
76. Taxes and insurance	2%	Installed cost	-	-	-	1,488
78. Depreciation (straight-line)						
Acid and oxygen plant	10.526%	Acid and oxygen plant related costs				5,889
Smelting	7.143%	Smelter related costs				1,336
79. Cost of funds or interest	10.00%	Total plant cost				7,440
80. Total operating cost[b,d]						34,349
82. Byproduct credit[e] - H_2SO_4	0.907 Mg (tons)	297,000 tons	20.00	3.27 (2.97)	65.4 (59.40)	-5,940
83. Byproduct credit[f] - steam	kWh	1.39×10^7	0.04	153.2 (139)	6.13 (5.56)	-556
90. Adjusted total operating costs with acid credit						28,409
91. Adjusted total operating costs with steam credit						33,793
92. Adjusted total operating costs with steam & acid credit						27,853

(continued)

TABLE 15 (continued)

	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	$ per Mg (ton) of copper	$1000/yr
100. Cost per kilogram (pound) of blister copper with acid & steam credit						0.3070 (0.1393)
101. Cost per kilogram (pound) of blister copper with steam credit but no acid credit[b,d]						0.3725 (0.1690)
102. Cost per kilogram (pound) of blister copper with steam credit and acid neutralization[b,d]						0.4464 (0.2025)

[a] Includes acid plant, oxygen plant, reduced blowing time at Peirce-Smith converters, material handling, gas and dust handling, and standby natural gas for heating (O-S furnace).

[b] Cost of ore or fluxes, land, or sludge disposal not included.

[c] For neutralization of acid plant sludge.

[d] Does not include depreciation and maintenance for Peirce-Smith converters and ancillaries or material handling, but does include steam credit.

[e] Either for sale (F.O.B. the smelter) or credited if utilized within the company or corporation.

[f] Steam generated from waste heat boiler, credited at the rate of 14,500 Btu/kWh and 40 mills per kWh.

TABLE 16. ANNUAL OPERATING COSTS OF CONVERTING A REVERBERATORY FURNACE PRODUCING 181,440 Mg (200,000 tons) OF BLISTER COPPER PER YEAR TO AN OXYGEN-SPRINKLE SYSTEM[a]

	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					$ per Mg (ton) of copper	$1000/yr
51. Raw materials[b] - lime[c]	0.907 Mg (tons)	17,400 tons	40.00	0.096 (0.087)	3.84 (3.48)	696
56. Direct labor	Hours	2,080 h/man	10.00	-	-	3,141
57. Supervision	15%	Direct labor	10.00	-	-	471
58. Maintenance labor	1.875%	Installed cost	-	-	-	2,378
59. Maintenance supervision	20%	Maintenance labor	-	-	-	476
60. Maintenance materials	2%	Installed cost	-	-	-	2,537
61. Operating supplies	20%	Plant maintenance	-	-	-	1,078
62. Payroll overhead	60%	Labor and supervision	-	-	-	3,880
63. Electricity	kWh	1.914×10^8	0.04	1055 (957.1)	42.2 (38.28)	7,657
64. Coal or oil	0.907 Mg (tons) 3.785 liters (gal)	23,472 tons 1.657×10^6 gal	35.00 1.00	0.129 (0.117) 34.6 (8.28)	4.53 (4.11) 9.13 (8.28)	822 1,657
65. Natural gas	28.3 m^3 (1000 ft^3)	24,000 M ft^3	2.50	0.003 (0.12)	0.33 (0.30)	60
66. Water - process	3785 liters (1000 gal)	1.354×10^5	0.34	2.69 (0.677)	0.27 (0.23)	46
67. Water - cooling	3785 liters (1000 gal)	6.64×10^7 M gal	0.06	1.385 (0.332)	0.022 (0.02)	4
71. Administration and overhead	40%	Labor, supervision, materials, and supplies	-	-	-	4,032
76. Taxes and insurance	2%	Installed cost	-	-	-	2,537
78. Depreciation (straight-line)						
Acid and oxygen plant	10.526%	Acid and oxygen plant related costs				9,444
Smelting	7.143%	Smelter related costs				2,652
79. Cost of funds or interest	10.00%	Total plant cost				12,685
80. Total operating cost[b,d]						56,253
82. Byproduct credit[e] - H_2SO_4	0.907 Mg (tons)	594,000 tons	20.00	3.27 (2.97)	65.4 (59.40)	-11,880
83. Byproduct credit[f] - steam	kWh	5.64×10^6	0.0028	3109 (2820)	8.8 (7.99)	-1,112
90. Adjusted total operating costs with acid credit						44,373
91. Adjusted operating costs with steam credit						55,141

(continued)

TABLE 16 (continued)

	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					$ per Mg (ton) of copper	$1000/yr
92. Adjusted total operating costs with steam & acid credit						43,261
100. Cost per kilogram (pound) of blister copper with acid & steam credit						0.2384 (0.1082)
101. Cost per kilogram (pound) of blister copper with steam creidt but no acid credit[b,d]						0.3039 (0.1379)
102. Cost per kilogram (pound) of blister copper with steam credit and acid neutralization[b,d]						0.3778 (0.1714)

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[a] Includes acid plant, oxygen plant, reduced blowing time at Peirce-Smith converters, material handling, gas and dust handling, and standby natural gas for heating (O-S furnace).

[b] Cost of ore or fluxes, land, or sludge disposal not included.

[c] For neutralization of acid plant sludge.

[d] Does not include depreciation and maintenance for Peirce-Smith converters and ancillaries or material handling, but does include steam credit.

[e] Either for sale (F.O.B. at the smelter) or credited within the company or corporation.

[f] Steam generated from waste heat boilers, credited at the rate of 14,500 Btu/kWh and 40 mills per kWh.

TABLE 17. ANNUAL OPERATING COSTS FOR CONVERTING A REVERBERATORY FURNACE PRODUCING 362,880 Mg (400,000 tons) OF BLISTER COPPER PER YEAR TO AN OXYGEN-SPRINKLE SYSTEM[a]

	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					$ per Mg (ton) of copper	$1000/yr
51. Raw materials[b] - lime[c]	0.907 Mg (tons)	34,800 tons	40.00	0.096 (0.087)	3.84 (3.48)	1,392
56. Direct labor	Hours	2,080 h/man	10.00	-	-	5,053
57. Supervision	15%	Direct labor	10.00	-	-	758
58. Maintenance labor	1.875%	Installed cost	-	-	-	4,464
59. Maintenance supervision	20%	Maintenance labor	-	-	-	893
60. Maintenance materials	2%	Installed cost	-	-	-	4,762
61. Operating supplies	20%	Plant maintenance	-	-	-	2,024
62. Payroll overhead	60%	Labor and supervision	-	-	-	7,379
63. Electricity	kWh	3.828×10^8	0.04	1055 (957.1)	42.2 (38.28)	15,312
64. Coal or oil	0.907 Mg (tons) 3.785 liters (gal)	46,944 tons 3.314×10^6 gal	35.00 1.00	0.129 (0.117) 34.6 (8.28)	4.53 (4.11) 9.13 (8.28)	1,643 3,314
65. Natural gas	28.3 m^3 (1000 ft^3)	48,000 M ft^3	2.50	0.003 (0.12)	0.33 (0.30)	120
66. Water - process	3785 liters (1000 gal)	2.708×10^5 M gal	0.34	2.82 (0.677)	0.27 (0.23)	92
67. Water - cooling	3785 liters (1000 gal)	1.328×10^5 M gal	0.06	1.385 (0.332)	0.022 (0.02)	8
71. Administration and overhead	40%	Labor, supervision, materials, and supplies	-	-	-	7,182
76. Taxes and insurance	2%	Installed cost	-	-	-	4,762
78. Depreciation (straight-line)						
Acid and oxygen plant	10.526%	Acid and oxygen plant related costs				18,419
Smelting	7.143%	Smelter related costs				4,509
79. Cost of funds or interest	10.00%	Total plant cost				23,810
80. Total operating cost[b,d]						105,896
82. Byproduct credit[e] - H_2SO_4	0.907 Mg (tons)	1.19×10^6 tons	20.00	3.27 (2.97)	65.4 (59.40)	-23,760
83. Byproduct credit[f] - steam	kWh	5.56×10^7	0.04	153.2 (139)	6.13 (5.56)	-2,224
90. Adjusted total operating costs with acid credit						82,136
91. Adjusted total operating with steam credit						103,672
92. Adjusted total operating costs with steam and acid credits						79,912

(continued)

TABLE 17 (continued)

	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					$ per Mg (ton) of copper	$1000/yr
100. Cost per kilogram (pound) of blister copper with acid and steam credit						0.2202 (0.0999)
101. Cost per kilogram (pound) of blister copper with steam credit but no acid credit[b,d]						0.2857 (0.1296)
102. Cost per kilogram (pound) of blister copper with steam credit and acid neutralization[b,d]						0.3595 (0.1631)

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[a] Includes acid plant, oxygen plant, reduced blowing time at Peirce-Smith converters, material handling, gas and dust handling, and standby natural gas for heating (O-S furnace).

[b] Cost of ore or fluxes, land, or sludge disposal not included.

[c] For neutralization of acid plant sludge.

[d] Does not include depreciation and maintenance for Peirce-Smith converters and ancillaries or material handling, but does include steam credit.

[e] Either for sale (F.O.B. the smelter) or credited within the company or corporation.

[f] Steam generated from waste heat boilers, credited at the rate of 14,500 Btu/kWh and 40 mills per kWh.

other plant usage. The acid plant is computed to have a capacity of approximately 792 Mg (873 tons) per day; however, a 1066-Mg (1175-ton) unit was selected to allow for short overlapping of two Peirce-Smith converters. A larger plant may be required to handle larger flows from their Peirce-Smith converters, but for this study the acid plant is oversized by approximately 25 percent. As shown in Table 14, the oxygen plant and sulfuric acid plant systems are again the major cost items and account for approximately 75 percent of the total capital costs for approximately 90,720 Mg (100,000 tons) per year of blister copper.

Total capital costs range from $656 to $820/Mg ($595 to $744/ton) of blister copper produced, depending on the size of the plant. Annualized costs range from $0.36 to $0.446/kg ($0.163 to $0.203/lb) of copper without credit for the sulfuric acid and neutralization of the acid.

OXYGEN-FUEL SMELTING

Existing reverberatory furnaces in primary copper smelters can be upgraded to operate with the oxygen-fuel reverberatory smelting technique developed by El Teniente Mining Division of CODELCO-CHILE at their smelter in Caletones, Chile.[27,28,29] This type of conversion increases throughput, decreases fuel requirements, produces an off-gas that is readily treatable for sulfur and particulate recovery, and reduces the total flow of gases to be handled.[30] Thus, it can also serve as a strategy for compliance with emission limitations.

Process Description

The technique of oxygen-fuel (oxy-fuel) smelting at Caletones started in 1970 to make use of an oxygen plant that had been installed for oxygen smelting in the converters. The original tests made in the Peirce-Smith converters failed to utilize the oxygen plant; however, some tests were also carried out in the reverberatory furnaces. In 1973, oxygen lance injection was tried with limited success.[30]

When the Caletones No. 3 reverberatory furnace came on line, oxy-fuel burners were installed in the roof and aimed directly at the charge slope (see Figure 10 for current configuration). (This basic type of burner had been basically used in the Onahama smelter in Japan, but with a different design.) The results were good there, and additional developments were made at Caletones. The current Caletones technique, which makes more efficient use of fuel input, reduces the total gas volume and increases the smelting rates.

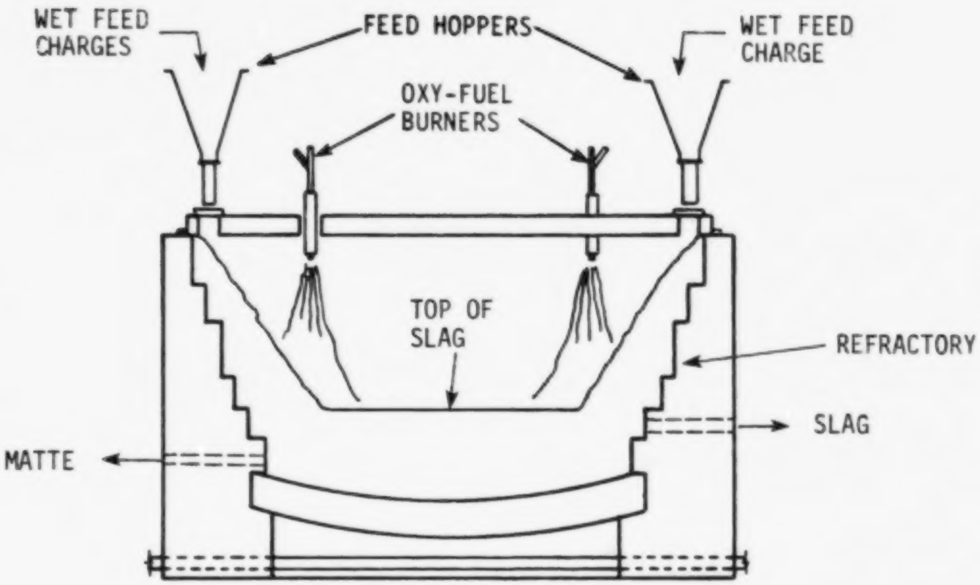
WET FEED CHARGES
FEED HOPPERS
WET FEED CHARGE
OXY-FUEL BURNERS
TOP OF SLAG
REFRACTORY
SLAG
MATTE

Figure 10. Location of oxy-fuel burners in reverberatory furnace.[22,23]

In 1976, a reverberatory furnace with a green-charge smelting capacity of 700 Mg (772 tons) per day (dry weight) was able to handle 1500 Mg (1653 tons) per day, and oil fuel consumption dropped from 180 kg per Mg (180 lb/ton to 80 kg/Mg (80 lb/ton) of the green charge when 12 oxy-fuel burners were used in the roof of the reverberatory furnace.

The Peirce-Smith converter (Figure 11) was redesigned. It was lengthened to 16.7 m (55 ft), the mouth was relocated near one end of the converter, and a feed port was installed at the opposite end for continuous charging of concentrate and flux. The tuyeres also were relocated so that none are near the openings for the mouth or the continuous feed port. Matte is introduced at a uniform loading frequency through the mouth of the modified converter. The slag take-off was placed at the end of the converter (in the vicinity of the mouth for matte charging), and the white metal (copper sulfide) was taken off at the opposite end of the converter; thus, no interruption occurs in blowing or feeding during the operation. After these modifications, the converter was called the El Teniente Modified Converter (TMC).[28,31]

Copper concentrate (39% copper) and matte (±50% copper) from the reverberatory furnace are fed to the TMC, which converts the charge to a white metal (73 to 75% copper).[27] The slag from this process is returned to the reverberatory furnace.[30] The white metal then is charged to a conventional Peirce-Smith converter for final treatment[30] (i.e., for the finish blow portion of the converting process to remove the remaining sulfur).

At 1300 Mg (1653 tons) per day versus 800 Mg per day (882 tons), the process fuel equivalent can be decreased by approximately 30 percent. This includes drying of the charge and using approximately 200 Mg (220 tons) per day of oxygen. Also, the productivity increases 62.5 percent.

The TMC process is somewhat similar to that of the Noranda smelting furnace, but the TMC utilizes a higher oxygen content in the blowing air injected through the tuyeres.

Experiments with the use of oxy-coal burners and concentrate burners showed good results. This technique is not expected to produce significant increases in the smelting rate, but rather a drop in the overall energy requirements.[30]

The SO_2 content of the gas to the acid plant from the oxy-fuel Caletones reverberatory furnace is 5.5 to 8 percent by volume, and a 10 to 12 percent SO_2 content for the TMC unit.[27] The TMC process utilizes the elongated Peirce-Smith converter for making white metal with a higher copper content input in the matte than most of the U.S. smelters. The capital costs in this study do not include conversion in the United States to the TMC

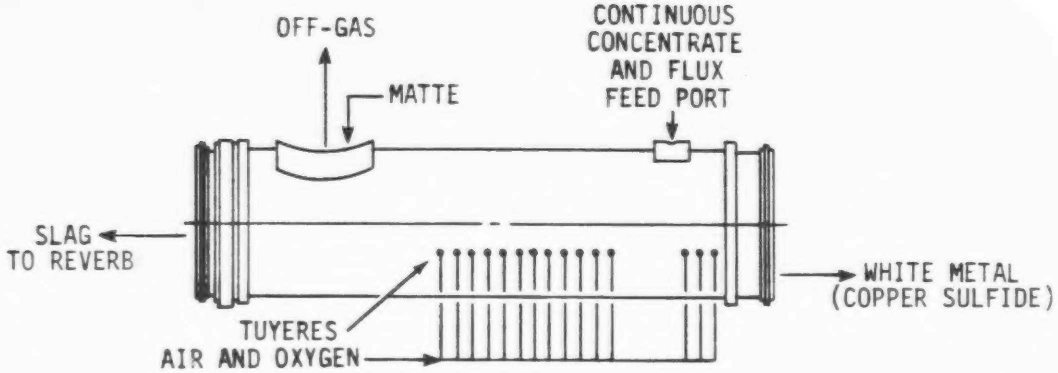
OFF-GAS
MATTE
CONTINUOUS CONCENTRATE AND FLUX FEED PORT
SLAG TO REVERB
WHITE METAL (COPPER SULFIDE)
TUYERES
AIR AND OXYGEN

Figure 11. Modified converter for oxygen smelting at Caletones smelter.[29,30]

unit. Because of the high copper content (39 percent) compared with the iron content (18 percent), sulfur content (26 percent), and a flux content (about 7 to 12 percent) in the concentrate reported at Caletones,[28,30] it is estimated that fuel requirements probably will decrease when U.S. ores (with their lower copper content and higher iron and sulfur content) are used because of the exothermic oxidation reactions of iron and sulfur. The higher SO_2 content would also decrease acid plant costs and process fuel equivalent requirements needed over those for a conventional reverberatory process with a Peirce-Smith converter generating 4 percent or less SO_2 content in the gas stream.

Figure 12 presents a schematic flow diagram of an oxygen-fuel smelting system without the TMC unit. Converting an existing reverberatory furnace to oxygen-fuel smelting depends on the following site-specific factors:

- Size and condition of the existing reverberatory furnace(s) and their immediate physical area and whether the furnace(s) can be replaced on a one-on-one basis without seriously disrupting production and operations
- Type and composition of the feed, which help to determine the matte grade, SO_2 off-gas volume, and amount of oxygen required.
- Plant configuration and available space to install an oxygen and sulfuric acid plant and (if necessary) a new building for the furnace and backup equipment with accessibility to existing converters and utilities
- Availability and size of the sulfuric acid plant at the site, if one exists
- Means of disposal of the sulfuric acid
- Maximum and minimum production requirements

Retrofitting

The major requirements for an oxy-fuel system are as follows:

- Blended feed to rotary or fluid bed dryer
- Particulate control system for dryer system
- Dry feed storage and reverberatory furnace roof feeding
- Natural gas or fuel oil supply to the roof area

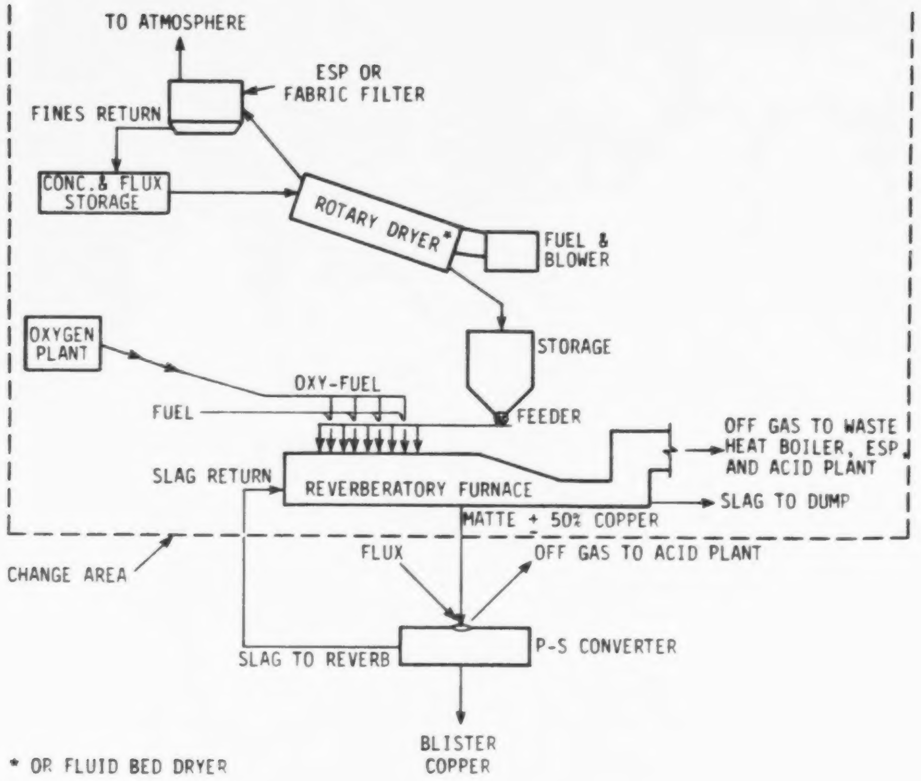
TO ATMOSPHERE
ESP OR FABRIC FILTER
FINES RETURN
CONC.& FLUX STORAGE
ROTARY DRYER*
FUEL & BLOWER
STORAGE
OXYGEN PLANT
OXY-FUEL
FUEL
FEEDER
OFF GAS TO WASTE HEAT BOILER, ESP, AND ACID PLANT
SLAG RETURN
REVERBERATORY FURNACE
SLAG TO DUMP
MATTE + 50% COPPER
CHANGE AREA
FLUX
OFF GAS TO ACID PLANT
SLAG TO REVERB
P-S CONVERTER
BLISTER COPPER
* OR FLUID BED DRYER

Figure 12. Flow diagram of oxy-fuel smelting system.

- Oxygen plant and supply to the roof area
- Reverberatory furnace revision if required at the uptake, additional matte and slag launders as required for increased tonnage of throughput
- Furnace roof redesign for burners and feeders
- Waste heat boiler redesign may be required for the decreased off-gas flow
- Exhaust gas ducting modification for flow control due to decreased off-gas flow
- Fines and slag return
- Acid plant and storage facilities
- Upgrading existing controls and new controls and appropriate respective instrumentation

Personnel for the new processing techniques and equipment will also have to be retrained.

Equipment requirements for handling approximately 326,000 Mg (360,000 tons) per year of concentrate for 90,720 Mg (100,000 tons) per year of blister copper are as follows:

- Two dryers for concentrate with particulate control systems
- Two (one operating, one standby) converted oxy-fuel reverberatory furnaces (42% matte) with about 8 percent SO_2 gas stream to acid plant
- Three (one or two operating and one standby) Peirce-Smith converters (gases 4% SO_2 to acid plant)
- Acid plant (approximately 5.0% SO_2 combined gases from the modified reverberatory furnace and Peirce-Smith converters to a double-contact acid plant)

If some of the sulfuric acid process equipment is currently in usable condition, overall modification costs for the sulfuric acid plant could decrease. Additionally, if a single-contact/single-absorption sulfuric acid plant is available with sufficient capacity to handle the gas flow, it may be possible to upgrade it by installing additional catalyst beds, another or final absorption tower, additional heat exchange pumps, blower modifications, tanks, and storage facilities, all of which are the major items that would be required for the upgrade.

Dry feed storage bins (either new or modified existing bins), feeders, and conveyors to the top of the reverberatory roof may be required. A vertical feed discharge is required from the roof top, along the inside walls of the reverberatory furnace. Oxy-fuel burners are positioned in the roof line, and the flame impinges on the feed discharged into the furnace and the bath (Figure 10). Additional burners may be installed in the end wall.

Oxygen-to-fuel ratios will vary depending on the throughput, the amount of sulfur and iron in the feed, and the percent copper required in the matte. Therefore, a computerized process control system is expected to aid in controlling the flow rates of the oxygen and/or fuel required for a particular feed rate and ore composition.

The refractory of the furnace would probably be rebuilt from the hearth up; the roof and shell may have to be modified for the oxy-fuel burners, for feeding of dried feed, and for Peirce-Smith converter slag return. Additional tap holes would be needed for slagging and tapping because of the increased input of concentrate and flux; alterations also may have to be made to the uptake and waste heat boilers because of the smaller gas flow from the furnace; and the furnace redesign should be made as tight as possible. Figure 13 shows some of the types of furnace modifications that were required at the Caletones smelter.[30]

Fines recovered from the waste-heat boiler and off-gas fines would be sent to the incoming raw material storage area for recycling; the percentage of fines carryover probably would be 3 to 5 percent of the concentrate charge.

The equivalent fuel energy requirement for materials handling; operation of the modified oxy-fuel reverberatory furnace, the Peirce-Smith converter, and the acid and oxygen plants; and the steam credit is 1,041,500 kcal per Mg (4,133,000 Btu per ton) of concentrate.

Cost

Table 18 presents a summary of the economic evaluation and a general description of the items requiring modification. The cost evaluation and descriptive segment for the conversion to the oxygen-fuel smelting includes the following:

- Facility description
- Capacity rating
- Abstract of scope

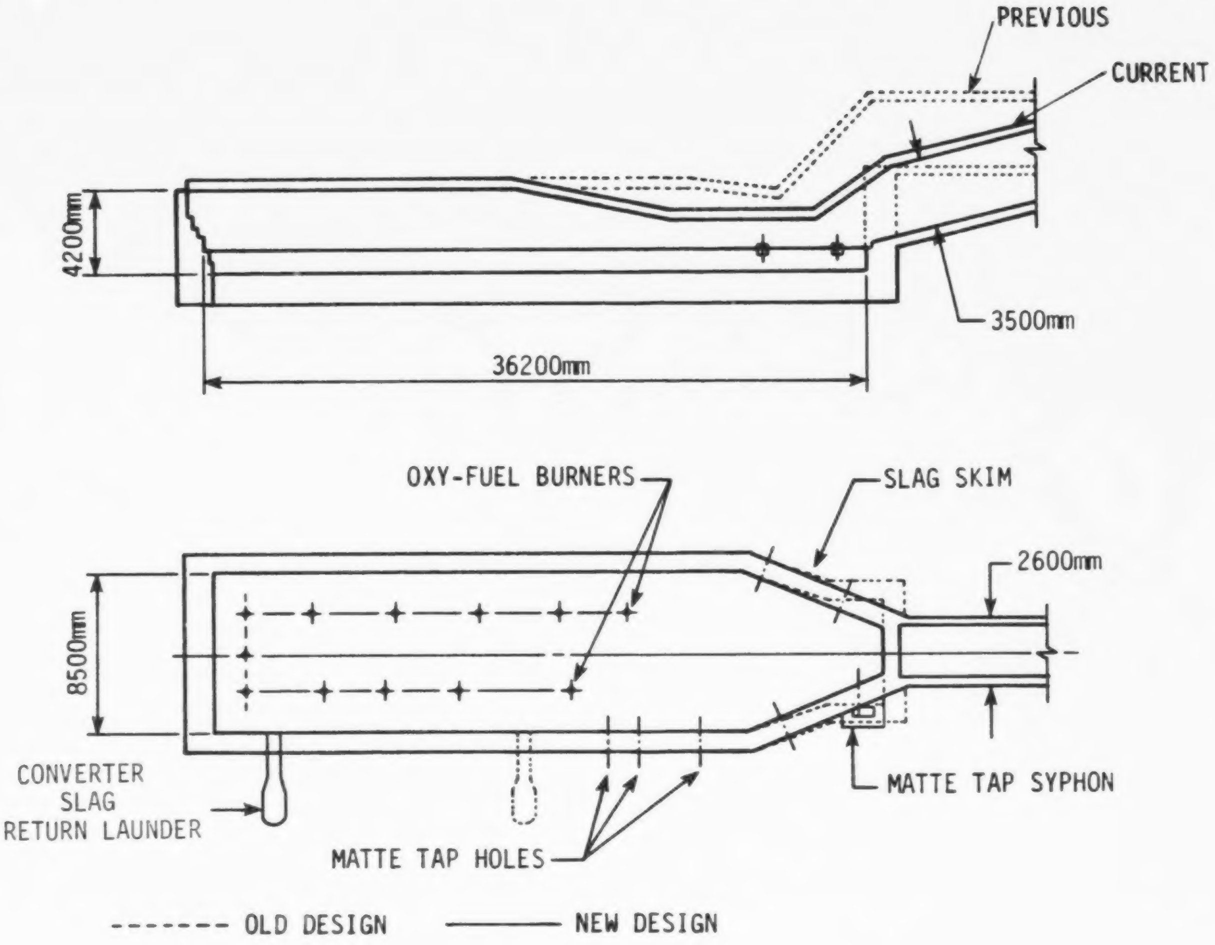
PREVIOUS
CURRENT
4200mm
3500mm
36200mm
OXY-FUEL BURNERS
SLAG SKIM
2600mm
8500mm
CONVERTER SLAG RETURN LAUNDER
MATTE TAP SYPHON
MATTE TAP HOLES
------- OLD DESIGN
——— NEW DESIGN

Figure 13. Plan and elevation of reverberatory furnace with oxygen-fuel smelting.[29]

TABLE 18. SUMMARY OF ECONOMIC EVALUATION FOR OXY-FUEL SYSTEM

DESCRIPTIVE SEGMENT	
Facility description	
Plant location	United States
Construction cost	General; not indexed for a specific area for labor costs
Capacity rating	
Blister copper	90,720 to 363,000 Mg/yr (100,000 to 400,000 tons/yr), handling 326,000 to 1,306,000 Mg/yr (±360,000 to 1,440,000 tons/yr) of copper concentrate. Cu ±29.5 percent.
Abstract of scope	
Plant basis	Retrofit of existing primary copper smelter reverberatory furnace(s). Removal of the existing furnace and installation of a modified reverberatory furnace and waste-heat boilers for an oxy-fuel smelting system without disrupting the overall plant's capacity during retrofit. Space available for installation of smaller ducting and cleaning equipment for gas handling of the new modified furnace(s). Available space for the addition of a 95 percent pure oxygen plant and a new double contact-double absorption sulfuric acid plant. Blending of the modified reverberatory gases of 8 percent SO_2 with 4 percent Peirce-Smith converter SO_2 off-gas for a combined flow of 5 percent SO_2 gas to the acid plant. Copper in matte 42 percent. Acid plant with rail/truck/5-day storage.
Performance specification	
Energy	No actual reduction in process equivalent kilocalories per Mg (Btu's per ton) of blister copper compared with the conventional wet-charge reverberatory furnace. This energy comparison includes oxygen and acid plant for oxygen-fuel smelting and no controls for SO_2 for a conventional wet-charge reverberatory furnace and its Peirce-Smith converters.

(continued)

TABLE 18 (continued)

Performance specification (continued)	
SO_2 emissions	94+ percent of the captured SO_2 is sent to the acid plant; 3 percent of SO_2 escapes as fugitives, remainder of sulfur in slag and particulate.
Stage of development	
Operating	Operational at CODELCO-Chile since the mid-1970's and may be installed to operate at the Phelps-Dodge plant at Morenci and New Cornelia.
COST EVALUATION SEGMENT	
Specified parameters	
Interest rate	Interest for the capital cost is shown for the first year at 10 percent.
Facility life and depreciation period	9.5 years for oxygen and acid plants (range 7.5 to 11.5 years) 14 years for the oxy-fuel smelting (range 11 to 17 years) [from DEPRECIATION, IRS Publication 534, rev. November 1982].
Construction time	2 years
Reference units for process costs	Weight of blister copper, kg (lb)
Reference time for costs	January 1983
Cost index	Chemical Engineering (CE)
Inflation or projected costs - future	1.08^x (where x = years from January 1983 CE Index) [equation is based on slope of CE Plant Cost Index for the past 5 years.]
Cost estimate - capital estimate	
Types of capital investment estimates	PEI cost files - vendor quotes, estimated fabrication costs/installations, and Bureau of Mines cost studies.

(continued)

TABLE 18 (continued)

Cost estimate - capital estimate (continued)	
Allowance for funds during construction	The equivalent of 10.5 percent for one year based on a 2-year construction period on borrowed money at 10 percent, payout 10 percent first 6 months, 35 percent at the end of 12 months, 75 percent at the end of 18 months, and 100 percent at the end of 24 months; 10 percent retained on major items until shakedown of the equipment is completed at the end of a 24-month period.
Cost Estimate - operating expense	Total operating expenses consist of utilities, operating and maintenance labor, supervision, overhead, supplies, maintenance materials, administration, taxes, insurance, depreciation, cost of capital but does not include the cost of fluxes or concentrate.
Time on stream	350 days/yr, approximately 8400 h/yr
Labor (operating)	$10.00/h, coverage hourly rate for all operators
Depreciation	Straight-line
Revenue	$22 Mg ($20/ton) sulfuric acid
Income tax rate	N.A.
Contingency	25 percent for process equipment, installation, engineering, startup, contractors fee, and off-site expenses (Note: Turnkey installation of the oxygen plant includes a 10 percent contingency and the acid plant includes a 12.5 percent contingency).

- Performance specification for energy and SO_2 emissions
- Stage of development
- Specified parameters for interest rate (cost of funds), facility life and depreciation, construction time, reference units for process costs, cost index reference, inflation, or projected costs for future prediction
- Background and AFDC for capital cost estimates
- Basis for annual operating costs, time onstream, labor rate, depreciation, revenue for byproducts

Tables 19 through 22 present the total installed capital and annual operating costs for converting a modified reverberatory furnace to oxy-fuel smelting. The capital and annual operating costs shown are estimates for converting reverberatory furnace(s) to produce 90,720 to 362,880 Mg (100,000 to 400,000 tons) per year of blister copper. The concentrate feed analysis is 31 percent sulfur, 29.5 percent copper, and 29 percent iron. The costs shown represent capital and annual operating costs that include a 222-Mg (245-ton) per day oxygen plant and a 1066-Mg (1175-ton) per day double-contact/double-absorption sulfuric acid plant handling a combined 8 percent SO_2 stream from an oxygen-fuel smelting furnace and a 4 percent SO_2 stream from the Peirce-Smith converters. All the costs (expressed in January 1983 dollars) are shown as part of the conversion. When necessary, costs were escalated to this point by using the Chemical Engineering Plant Cost Index (315.5). These costs are based on vendor data, previous in-house estimates, and Bureau of Mines information. The costs include fixed charges for depreciation, cost of capital, interest costs during construction, equipment startup, and spares. The oxygen plant is based on 95 percent purity, 95 percent utilization, and 1 percent excess for other plant usage. The acid plant is oversized by 26 percent to handle surges from two overlapping Peirce-Smith converters. As shown in Table 19, the oxygen plant and sulfuric acid plant systems are the major cost items and account for the largest percentage of the total capital costs. Capital costs range from \$738 to \$900/Mg (\$670 to \$817/ton) of product, depending on plant size. Annualized costs range from \$0.34 to \$0.42/kg (\$0.15 to \$0.19/lb) of copper produced without credit for sulfuric acid but utilizing steam credit.

OTHER PROCESSES

Several other processes warrant consideration as possible ways to achieve reduced SO_2 emissions, profitable operating

TABLE 19. ESTIMATE OF CAPITAL INVESTMENT FOR CONVERTING A CONVENTIONAL REVERB TO A MODIFIED REVERBERATORY FURNACE FOR OXYGEN-FUEL SMELTING SYSTEM

	Factor	Item	Blister copper, Mg (tons)[a] per year		
			90,720[b] (100,000)	181,440[c] (200,000)	362,880[d] (400,000)
1. Equipment cost - F.O.B. job site					
Rotary dryers, ESP(s), dust-removal screw conveyors, modified reverberatory furnace configurations, and modified waste-heat boilers with ancillaries, ducting, hot ESP(s), hood for launders and ladles at furnace, etc.			$ 5,646,000	$ 11,416,200	$ 20,608,900
2. Installation	0.456	1	2,574,600	5,205,800	8,622,100
3. Piping, insulation	0.084	1&2	690,500	1,396,200	2,455,400
4. Electrical, instrumentation	0.081	1&2	665,900	1,346,400	2,367,700
5. Foundations, painting, misc.	0.048	1&2	394,600	797,900	1,403,100
6. Structural building alterations			73,600	140,300	271,600
7. Site clearance - partial removal of existing reverb, ductwork			294,400	597,600	1,245,800
8. Turnkey - oxygen plant			9,877,600	18,771,400	37,542,800
9. Turnkey - acid plant [1066 Mg/day at 5.0 percent SO_2 for 90,720 Mg/yr of copper]			48,000,000	74,000,000	148,000,000
10. Misc. - battery limits for Items 8 and 9	0.009	8&9	520,900	834,900	1,169,900
11. Equipment costs (installed)			68,738,100	114,506,700	224,187,300

(continued)

TABLE 19 (continued)

	Factor	Item	Blister copper, Mg (tons)[a] per year		
			90,720[b] (100,000)	181,440[c] (200,000)	362,880[d] (400,000)
Indirect Costs					
12. Engineering	0.10	1-7,10	1,086,100	2,173,500	3,864,500
13. Startup	0.035	1-7,10	380,100	760,700	1,352,600
22. Contractor's fee and offsite	0.05	1-7,10	543,000	1,086,800	1,932,200
23. Contingency	0.25	1-7,10, 12,13,22	3,217,400	6,439,100	11,448,500
24. Interest during construction	0.105	11-13, 22,23	7,766,300	13,121,500	25,492,400
30. Total indirect costs			$12,992,900	$ 23,581,600	$ 44,090,200
31. TOTAL INSTALLED PLANT COSTS			$81,731,000	$138,088,300	$268,277,500

[a] Ton = 2000 pounds.

[b] One oxy-fuel type furnace; no modification to Peirce-Smith converters.

[c] Two oxy-fuel type furnaces; no modification to Peirce-Smith converters.

[d] Three oxy-fuel type furnaces. (No facility in the United States has a capacity of 362,880 Mg (400,000 tons/year).

TABLE 20. ANNUAL OPERATING COSTS FOR CONVERTING A REVERBERATORY FURNACE PRODUCING 90,720 Mg (100,000 tons) OF BLISTER COPPER PER YEAR TO AN OXYGEN-FUEL SYSTEM[a]

	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					$ per Mg (ton) of copper	$1000/yr
51. Raw materials[b] - lime[c]	0.907 Mg (tons)	8,700 tons	40.00	0.096 (0.087)	3.84 (3.48)	348
56. Direct labor (134 people)	Hours	2,080 h/man	10.00	-	-	2,787
57. Supervision	15%	Direct labor	10.00	-	-	418
58. Maintenance labor	1.875%	Installed cost	-	-	-	1,532
59. Maintenance supervision	20%	Maintenance labor	-	-	-	306
60. Maintenance materials	2%	Installed cost	-	-	-	1,635
61. Operating supplies	20%	Plant maintenance	-	-	-	695
62. Payroll overhead	60%	Labor and supervision	-	-	-	3,026
63. Electricity	kWh	6.696×10^7	0.04	738.1 (669.6)	29.5 (26.79)	2,679
64. Oil	3.78 liters (gal)	5.208×10^6 gal	1.00	217.3 (52.08)	57.4 (52.08)	5,208
65. Natural gas	28.3 m^3 (1000 ft^3)	18,000 M ft^3	2.50	0.006 (0.18)	0.50 (0.45)	45
66. Water - process	3785 liters (1000 gal)	7.42×10^4 M gal	0.34/ 1000 gal	3.1 (0.742)	0.28 (0.25)	25
67. Water - cooling	3785 liters (1000 gal)	3.13×10^4 M gal	0.06/ 1000 gal	1.306 (0.313)	0.022 (0.02)	2
71. Administration and overhead	40%	Labor, supervision, materials, and supplies	-	-	-	2,949
76. Taxes and insurance	2%	Installed cost	-	-	-	1,635
78. Depreciation (straight-line)						
Acid and oxygen plant	10.526%	Installed cost of acid and oxygen plant related costs				6,792
Smelting	7.143%	Installed cost of smelter related costs				1,229
79. Cost of funds of interest	10.00%	Total installed cost				8,173
80. Total operating cost[b,d]						38,484
82. Byproduct credit[e] - H_2SO_4	0.907 Mg (tons)	297,000 tons	20.00	3.27 (2.97)	65.4 (59.40)	-5,940
83. Byproduct credit[f] - steam	kWh	2.596×10^7	0.04	(259.6)	(10.38)	-1,038
90. Adjusted total operating costs with acid credits						33,544
91. Adjusted total operating costs with steam credits						38,446
92. Adjusted total operating costs with steam and acid credits						32,506

(continued)

TABLE 20 (continued)

	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					$ per Mg (ton) of copper	$1000/yr
100. Cost per kilogram (pound) of blister copper with acid and steam credit						0.3583 (0.1625)
101. Cost per kilogram (pound) of blister copper with steam credit but no acid credit[b,d]						0.4238 (0.1922)
102. Cost per kilogram (pound) of blister copper with steam credit and acid neutralization[b,d]						0.4976 (0.2257)

[a] Includes acid plant, oxygen plant, reduced blowing time at Peirce-Smith converters, material handling, gas and dust handling, and standby natural gas for heating (O-S furnace).

[b] Cost of ore or fluxes, land, or sludge disposal not included.

[c] For neutralization of acid plant sludge.

[d] Does not include depreciation and maintenance for Peirce-Smith converters and ancillaries or material handling, but does include steam credit.

[e] Either for sale (F.O.B. at the smelter) or credited if utilized within the company or corporation.

[f] Steam generated from waste heat boiler, credited at the rate of 14,500 Btu/kWh[3] and 40 mills per kWh.

TABLE 21. ANNUAL OPERATING COSTS OF CONVERTING A REVERBERATORY FURNACE PRODUCING 181,440 Mg (200,000 tons) OF BLISTER COPPER PER YEAR TO AN OXYGEN-FUEL SYSTEM[a]

					Total costs	
	Unit	Units/yr	\$/unit	Units per basic unit of Cu, Mg (tons)	\$ per Mg (ton) of copper	\$1000/yr
51. Raw materials[b] - lime[c]	0.907 Mg (tons)	17,400 tons	40.00	0.096 (0.087)	3.84 (3.48)	696
56. Direct labor	Hours	2,080 h/man	10.00	-	-	3,141
57. Supervision	15%	Direct labor	10.00	-	-	471
58. Maintenance labor	1.875%	Installed cost	-	-	-	2,589
59. Maintenance supervision	20%	Maintenance labor	-	-	-	518
60. Maintenance materials	2%	Installed cost	-	-	-	2,762
61. Operating supplies	20%	Plant maintenance	-	-	-	1,174
62. Payroll overhead	60%	Labor and supervision	-	-	-	4,031
63. Electricity	kWh	1.339 x 10^8	0.04	738.1 (669.6)	29.5 (26.79)	5,356
64. Oil	3.78 liters (gal)	1.042 x 10^7 gal	1.00	102.9 (52.08)	57.4 (52.08)	10,416
65. Natural gas	28.3 m^3 (1000 ft^3)	36,000 M ft^3	2.50	0.006 (0.18)	0.50 (0.45)	90
66. Water - process	3785 liters (1000 gal)	1.484 x 10^3	0.34/ 1000 gal	3.1 (0.742)	0.28 (0.25)	50
67. Water - cooling	3785 liters (1000 gal)	6.26 x 10^4	0.06/ 1000 gal	1.306 (0.313)	0.022 (0.02)	4
71. Administration and overhead	40%	Labor, supervision, materials, and supplies	-	-	-	4,262
76. Taxes and insurance	2%	Installed cost	-	-	-	2,762
78. Depreciation (straight-line)						
Acid and oxygen plant	10.526%	Installed cost of acid related costs				10,888
Smelting	7.143%	Installed cost of smelter related costs				2,475
79. Cost of funds or interest	10.00%	Total installed cost				13,809
80. Total operating cost[b,d]						65,494
82. Byproduct credit[e] - H_2SO_4	0.907 Mg (tons)	297,000 tons	20.00	3.27 (2.97)	65.4 (59.40)	-11,880
83. Byproduct credit[f] - steam	kWh	2.596 x 10^7	0.04	286.2 (259.6)	11.44 (10.38)	-2,076
90. Adjusted total operating costs with acid credits						53,614
91. Adjusted total operating costs with steam credits						63,418

(continued)

TABLE 21 (continued)

	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					$ per Mg (ton) of copper	$1000/yr
92. Adjusted total operating costs with steam and acid credits						51,538
100. Cost per kilogram (pound) of blister copper with acid and steam credit						0.2840 (0.1288)
101. Cost per kilogram (pound) of blister copper with steam credit but no acid credit[b,d]						0.3495 (0.1585)
102. Cost per kilogram (pound) of blister copper with steam credit and acid neutralization[b,d]						0.4234 (0.1920)

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[a] Includes acid plant, oxygen plant, reduced blowing time at Peirce-Smith converters, material handling, gas and dust handling, and standby natural gas for heating (O-S furnace).

[b] Cost of ore or fluxes, land, or sludge disposal not included.

[c] For neutralization of acid plant sludge.

[d] Does not include depreciation and maintenance for Peirce-Smith converters and ancillaries or material handling, but does include steam credit.

[e] Either for sale (F.O.B. at the smelter) or credited if utilized within the company or corporation.

[f] Steam generated from waste heat boiler(s), credited at the rate of 14,500 Btu/kWh and 40 mills per kWh.

TABLE 22. ANNUAL OPERATING COSTS OF CONVERTING A REVERBERATORY FURNACE PRODUCING 362,880 Mg (400,000 tons) OF BLISTER COPPER PER YEAR TO AN OXYGEN-FUEL SYSTEM[a]

	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					$ per Mg (ton) of copper	$1000/yr
51. Raw materials[b] - lime[c]	0.907 Mg (tons)	34,800 tons	40.00	0.096 (0.087)	3.84 (3.48)	1,392
56. Direct labor	Hours	2,080 h/man	10.00	-	-	5,614
57. Supervision	15%	Direct labor	10.00	-	-	842
58. Maintenance labor	1.875%	Installed cost	-	-	-	5,030
59. Maintenance supervision	20%	Maintenance labor	-	-	-	1,006
60. Maintenance materials	2%	Installed cost	-	-	-	5,366
61. Operating supplies	20%	Plant maintenance	-	-	-	2,280
62. Payroll overhead	60%	Labor and supervision	-	-	-	7,495
63. Electricity	kWh	2.678×10^8	0.04	738.1 (669.6)	29.5 (36.79)	10,712
64. Oil	3.78 liters (gal)	2.084×10^7 gal	1.00	217.3 (52.08)	57.4 (52.08)	20,832
65. Natural gas	28.3 m^3 (1000 ft^3)	72,000 M ft^3	2.50	0.006 (0.18)	0.50 (0.45)	180
66. Water - process	3785 liters (1000 gal)	2.968×10^5 M gal	0.34/ 1000 gal	3.1 (0.742)	0.28 (0.25)	100
67. Water - cooling	3785 liters	1.252×10^5 M gal	0.06/	1.306 (0.313)	0.022 (0.02)	8
71. Administration and overhead	40%	Labor, supervision, materials, and supplies	-	-	-	8,055
76. Taxes and insurance	2%	Installed cost	-	-	-	5,366
78. Depreciation (straight-line)						
Acid and oxygen plant	10.526%	Installed cost of acid and oxygen plant related costs				21,775
Smelting	7.143%	Installed cost of smelter related costs				4,386
79. Cost of funds or interest	10.00%	Total installed cost				26,828
80. Total operating cost[b,d]						127,267
82. Byproduct credit[e] - H_2SO_4	0.907 Mg (tons)	1.188×10^6 tons	20.00	3.27 (2.97)	65.4 (59.40)	-23,760
83. Byproduct credit[f] - steam	kWh	5.192×10^7	0.04	2862 (259.6)	11.44 (10.38)	-4,152
90. Adjusted total operating costs with acid credits						103,507
91. Adjusted total operating costs with steam credits						123,115

(continued)

TABLE 22 (continued)

	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					$ per Mg (ton) of copper	$1000/yr
92. Adjusted total operating costs with steam and acid credits						99,355
100. Cost per kilogram (pound) of blister copper with acid and steam credit						0.2738 (0.1242)
101. Cost per kilogram (pound) of blister copper with steam credit but no acid credit[b,d]						0.3393 (0.1539)
102. Cost per kilogram (pound) of blister copper with steam credit and acid neutralization[b,d]						0.4131 (0.1874)

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[a] Includes acid plant, oxygen plant, reduced blowing time at Peirce-Smith converters, material handling, gas and dust handling, and standby natural gas for heating (O-S furnace).

[b] Cost of ore or fluxes, land, or sludge disposal not included.

[c] For neutralization of acid plant sludge.

[d] Does not include depreciation and maintenance for Peirce-Smith converters and ancillaries or material handling, but does include steam credit.

[e] Either for sale (F.O.B. the smelter) or credited if utilized with the company or corporation.

[f] Steam generated from waste heat boiler(s), credited at the rate of 14,500 Btu/kWh and 40 mills per kWh.

costs, and energy operation. Some of these are discussed here. Because of the number and diversity of these processes and the time constraints, they are discussed in less detail, however.

Costs were developed for 90,720 Mg (100,000 tons) per year of anode copper production in the Noranda process with oxygen enrichment (70 to 75 percent matte), the Outokumpu Oy process with oxygen enrichment (60 to 65 percent matte), and the Mitsubishi continuous smelting system (blister copper).

The following available processes were not analyzed in regard to cost, energy, and SO_2 emissions as part of this project:

- The electric arc furnace for primary smelting, with dryer, and Peirce-Smith converters
- Noranda single-step reactor (blister copper)
- The top-blown rotating converter (Kaldo)
- Outokumpu Oy with preheated air
- Flame cyclone process by Lurgi
- Contop process
- Combined oxygen fuel and oxygen sprinkle smelting
- Gravity and continuous process flow with Hoboken converters
- Amax Dead Roast Blast furnace smelting
- Worca continuous smelting with oxygen lances
- Kivcet process

The Noranda Process[31-34]

The Noranda process can operate on a continuous basis, during which smelting and converting take place in a 5.2-m diameter by 21-m (17-ft by 70-ft) refractory-lined cylinder similar to a Peirce-Smith converter. This process can also be operated to produce a matte grade of 70 to 75 percent copper, and then followed by Peirce-Smith converter(s) to form blister copper, as shown in Figure 14. This process is practiced by Kennecott at its Utah smelter.[34] At this plant, the Noranda furnace (Figure 15) has 63 tuyeres below the matte surface, oxygen enrichment to increase the oxygen content of the blast air to 23.4 percent, and a fuel rate of 7.42×10^5 kcal/Mg (2.67×10^6 Btu/ton) of copper concentrate. A belt slinger introduces the pelletized feed, including coal, into one end of the reactor. Additional fuel and air are also introduced in this end through the burners. At the opposite end, where the slag is removed, are additional fuel and air burners. Matte is tapped from the front of the reactor. Oxygen-enriched air is blown into the matte layer through the side-mounted tuyeres. The reactor can be rotated in the same manner as the Peirce-Smith converters. The removed slag, which contains 6 to 8 percent copper, is milled to produce a concentrate that is returned to the reactor. The off-gases

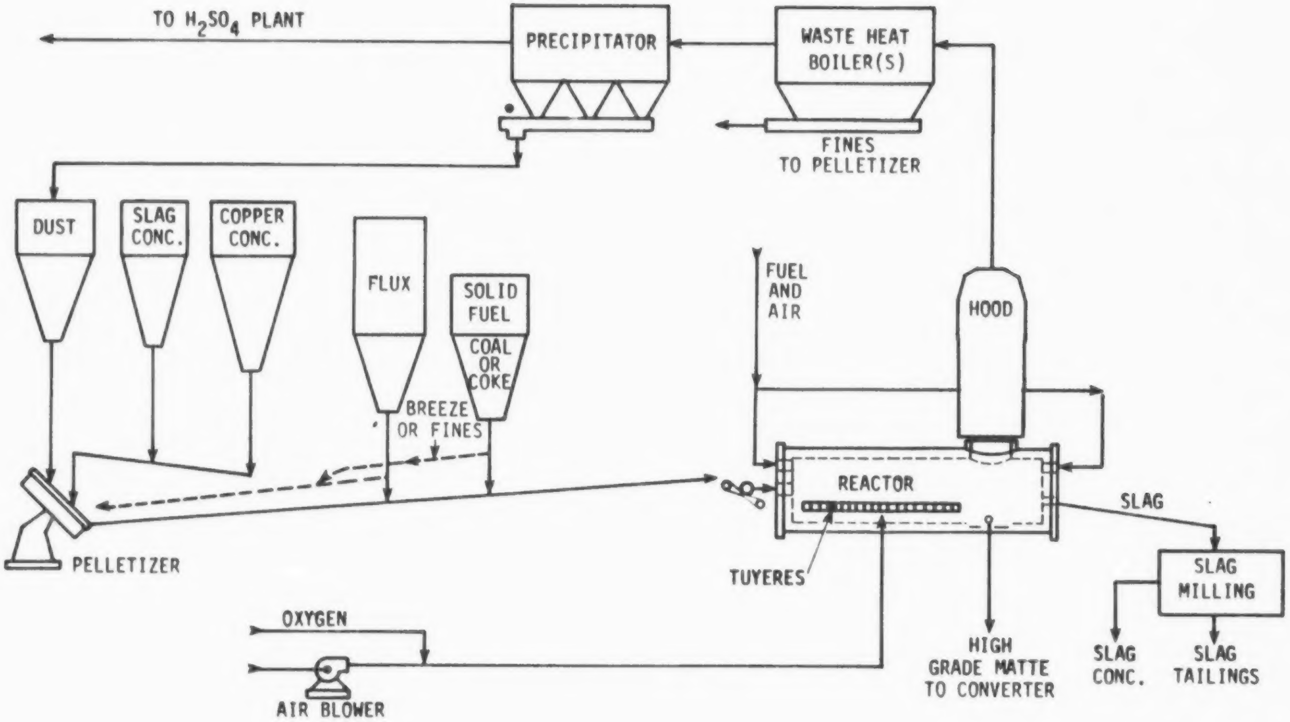
TO H_2SO_4 PLANT
PRECIPITATOR
WASTE HEAT BOILER(S)
FINES TO PELLETIZER
DUST
SLAG CONC.
COPPER CONC.
FLUX
SOLID FUEL
COAL OR COKE
BREEZE OR FINES
FUEL AND AIR
HOOD
REACTOR
SLAG
SLAG MILLING
PELLETIZER
TUYERES
OXYGEN
AIR BLOWER
HIGH GRADE MATTE TO CONVERTER
SLAG CONC.
SLAG TAILINGS

Figure 14. Noranda process flow diagram.[33]

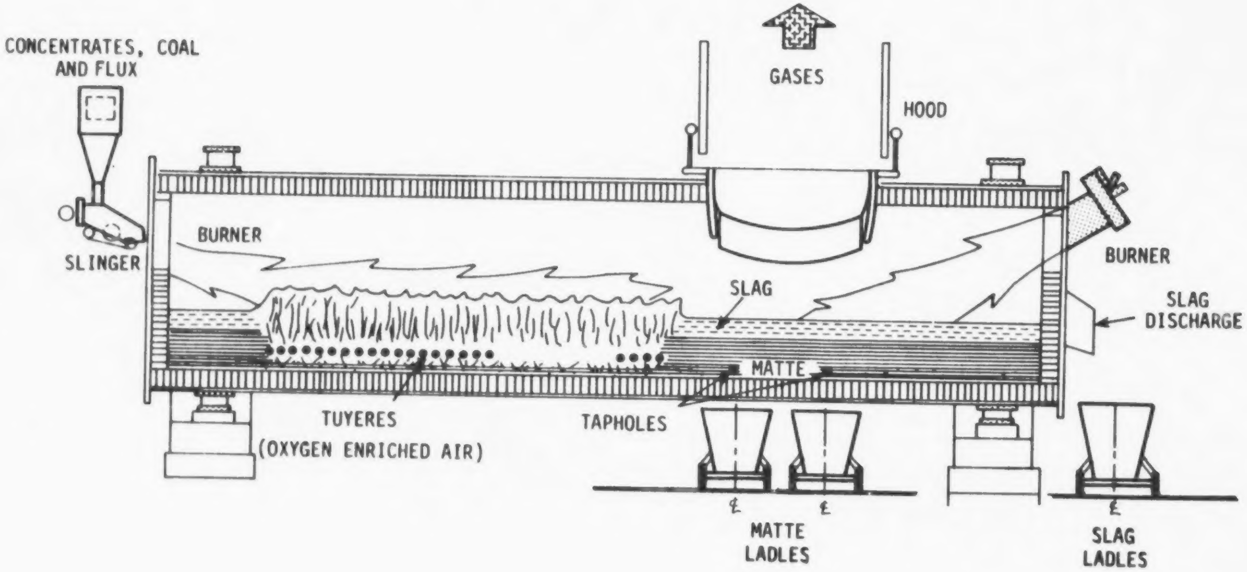
CONCENTRATES, COAL AND FLUX
GASES
HOOD
BURNER
SLINGER
BURNER
SLAG
SLAG DISCHARGE
MATTE
TUYERES
(OXYGEN ENRICHED AIR)
TAPHOLES
MATTE LADLES
SLAG LADLES

Figure 15. Cross section of Noranda furnace.

leave the Noranda furnace through its mouth, where they are captured by water-cooled hoods and ducted to a waste-heat boiler. The gases are passed through cyclones and electrostatic precipitators to remove particulate matter, and then sent to a sulfuric acid plant. The blended gas streams from the Noranda reactor and the Peirce-Smith converters would have a sulfur dioxide concentration of about 6.7 percent. If the combustion air is 35 percent oxygen-enriched, the off-gases to the acid plant can contain approximately 11 percent SO_2; without oxygen-enriched air, the SO_2 concentration would be approximately 4 percent.

Based on data presented by Kellogg and Henderson,[10] the equivalent energy this process requires for the oxygen, fuel, and acid plant to produce anode copper is 9.92×10^5 kcal/Mg (3.57×10^6 Btu/ton) per ton of concentrate with a converter gas stream of 9.4 percent SO_2. If the converter off-gas were 4 percent, however, the equivalent energy value would be 1.03×10^6 kcal/Mg (3.72×10^6 Btu/ton) per ton of concentrate. This is about 75 percent of the energy required by a smelter with an uncontrolled conventional reverberatory furnace.[10]

Retrofitting an existing smelter's conventional reverberatory furnace with the Noranda furnace can become costly if all new building facilities are included because the reverberatory furnace must be completely removed.

If a smelter were able to use the existing facilities and the space occupied by an existing reverberatory furnace(s), the following major process equipment modifications would be required to handle 907 Mg (1000 tons) of concentrate per day:

- Installation of pelletizers, blending area, coal/coke handling system
- Installation of an oxygen plant in the approximate vicinity of the reverberatory furnace area
- Possible relocation of day bins, and weighing and handling of all feed components for and to the furnace
- Space for acid plant/gas cleaning. If an acid plant already exists, modifications may be necessary for the higher-strength gases. These modifications are similar to those reported for the INCO process (as discussed earlier in this section)
- Alterations (if necessary) to the existing reverberatory waste-heat boilers, ducting, piping, etc.
- Control and instrument installation and modifications
- Process operational changes to Peirce-Smith converters for decreased blowing time

Personnel would have to be trained for the new process equipment and operating techniques.

Copper conversion costs will vary considerably from plant to plant because of site-specific factors. Table 23 presents a capital cost estimate for installing a Noranda furnace in a smelter currently producing 90,720 Mg (100,000 tons) of blister copper, and Table 24 presents the annual smelting operating costs.

The Noranda furnace would produce a matte containing 70 to 75 percent copper for subsequent processing in a Peirce-Smith converter. The data in Table 23 show a total cost of about $76,516,800; about half of this cost ($35,900,000) is due to the sulfuric acid plant. Total annual operating costs with steam and without acid credits are $31,071,000 or $0.34/Mg ($0.16/ton) of anode copper product.

Outokumpu Oy Process

Two techniques have been used in the operation of the Outokumpu Oy primary smelting furnace--preheating the combustion air and using oxygen-enriched air, as shown in Figure 16.[35,36] Figure 17 presents a process flow diagram that shows both arrangements.

In this process, the feed (including flux) is introduced in the top of the reaction shaft, and depending on whether oxygen enrichment or preheated air is injected with the oil, the finely divided concentrate burns as the particles fall down through the shaft. Heat is generated from either the combustion of the oil and sulfur or from the oxidation of iron and sulfur when oxygen enrichment is used. The molten particles fall into the settler part of the furnace and separate into matte and slag layers. The matte, which can contain 45 to 75 percent copper, is tapped from the settler and transferred to converters for further processing. The slag, which contains too much copper to be discarded, can be processed (by milling, etc.) and recycled. Outlet gases from the Outokumpu Oy furnace, which can contain 6 to 30 percent SO_2, leave the furnace through the uptake stack. These gases contain a high carryover of fines, and the gases and particulates are partially cooled in the waste-heat boiler before being passed through an ESP and on to the acid plant. Most of the fines that are removed at the waste-heat boiler and at the ESP are returned for reprocessing through the furnace.

These furnace gases are combined with the Peirce-Smith converter gases and sent to the acid plant. The combined SO_2 content is about 6.7 percent.

TABLE 23. ESTIMATED CAPITAL COST OF RETROFITTING A REVERBERATORY FURNACE WITH A NORANDA FURNACE PRODUCING A MATTE CONTAINING 70 to 75 PERCENT COPPER IN A SMELTER PRODUCING 90,720 Mg (100,000 tons)[a] OF BLISTER COPPER PER YEAR

Item	Factor	Item	Cost, $
1. Equipment cost - FOB job site			
Blending area, coal/coke preparation, alteration to storage bins, conveyors, Noranda furnace(s)[b] and ancillaries, hooding, feeders, burners, cooling chamber, ESP(s), waste-heat boiler, modifications, ducting, pelletizer(s), material and coal handling, slag (copper) recovery, etc.			8,257,400
2. Installed, erected equipment	0.456	1	3,765,400
3. Piping, insulation	0.084	1&2	1,003,900
4. Electrical, instrumentation	0.081	1&2	973,800
5. Foundations, painting, miscellaneous items	0.048	1&2	577,100
6. Structural building alterations			187,800
7. Site clearance - remove existing reverb, ductwork			653,400
8. Turnkey - oxygen plant [0.8 kg O_2/kg Cu (0.8 lb O_2/lb Cu)]			9,887,600
9. Turnkey - acid plant 1066 Mg (1175 tons) capacity			35,900,000
10. Miscellaneous - battery limits	0.009	8&9	412,100
11. Equipment costs (installed)			61,624,500
Indirect Costs			
12. Engineering	0.10	1-7,10	1,583,700
13. Startup	0.035	1-7,10	554,300
22. Contractor's fee and offsite	0.05	1-7,10	791,800
23. Contingency	0.25	1-7,10, 12, 13, 22	4,691,700
24. Interest during construction	0.105	11-13,	7,270,800
30. Total indirect costs		22, 23	14,892,300
31. TOTAL PLANT COSTS			$ 76,516,800

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[a] Ton = 2000 pounds.

[b] One-furnace operation, Noranda type with reduced Peirce-Smith converter(s) operation.

TABLE 24. ANNUAL OPERATING COSTS FOR RETROFITTING A REVERBERATORY FURNACE WITH A NORANDA FURNACE PRODUCING A MATTE CONTAINING 70 TO 75 PERCENT COPPER WITH A CAPACITY OF 90,720 Mg (100,000 tons) OF BLISTER COPPER PER YEAR[a]

					Total costs	
	Unit	Units/yr	\$/unit	Units per basic unit of Cu, Mg (tons)	\$ per Mg (ton) of copper	\$1000/yr
51. Raw materials[b] - lime[c]	0.907 Mg (tons)	8,700 tons	40.00	0.096 (0.087)	3.84 (3.48)	348
56. Direct labor (134 people)	Hours	2,080 h/man	10.00			2,496
57. Supervision	15%	Direct labor	10.00			374
58. Maintenance labor	1.875%	Installed cost				1,435
59. Maintenance supervision	20%	Maintenance labor				287
60. Maintenance materials	2%	Installed cost				1,530
61. Operating supplies	20%	Plant maintenance				650
62. Payroll overhead	60%	Labor and supervision				2,755
63. Electricity	kWh	5.905×10^7	0.04	650.9 (590.5)	26.04 (23.62)	2,362
64. Oil	3.78 liters (gal)	2.236×10^6 gal	1.00	7.20 (6.53)	7.20 (6.53)	2,236
65. Natural gas	28.3 m^3 (1000 ft^3)	12,000 M ft^3	2.50	0.003 (0.12)	0.33 (0.30)	30
66. Water - process	3,785 liters (1000 gal)	7.42×10^4 M gal	0.34	3.1 (0.742)	0.28 (0.25)	25
67. Water - cooling	3,785 liters (1000 gal)	3.36×10^4 M gal	0.06	1.385 (0.332)	0.022 (0.02)	2
71. Administration and overhead	40%	Labor, supervision, materials, and supplies				2,709
76. Taxes and insurance	2%	Installed cost				1,530
78. Depreciation (straight-line)						
Acid and oxygen plant	10.526%	Acid and oxygen plant costs				5,374
Smelting equipment	7.143%	Smelter costs				1,821
79. Cost of funds or interest	10.00%	Total plant cost				7,652
80. Total operating cost[b,d]						31,795
82. Byproduct credit[e] - H_2SO_4	0.907 Mg (tons)	297,000 tons	20.00	3.27 (2.97)	65.48 (59.40)	-5,940
83. Byproduct credit[f] - steam	0.45 kg (lb)	1.81×10^7	0.04	199.5 (181)	7.98 (7.24)	-724
90. Adjusted total operating costs with acid credit						25,855
91. Adjusted total operating costs with steam credit						31,071
92. Adjusted total operating costs with steam and acid credit						25,131

(continued)

TABLE 24 (continued)

	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					$ per Mg (ton) of copper	$1000/yr
100. Cost per kilogram (pound) of blister copper with steam and acid credit						0.2770 (0.1257)
101. Cost per kilogram (pound) of blister copper with steam credit but no acid credit[b,d]						0.3425 (0.1554)
102. Cost per kilogram (pound) of blister copper with steam credit and acid neutralization[b,d]						0.4164 (0.1889)

[a] Includes acid plant, oxygen plant, reduced blowing time at Peirce-Smith converters, material handling, gas and dust handling, and standby natural gas for heating.

[b] Cost of ore or fluxes, land, or sludge disposal not included.

[c] For neutralization of acid plant sludge.

[d] Does not include depreciation and maintenance for Peirce-Smith converters and ancillaries or material handling, but does include steam credit.

[e] Either for sale (F.O.B. the smelter) or credited if utilized within the company or corporation.

[f] Steam generated from waste heat boiler(s), credited at the rate of 14,500 Btu/kWh[3] and 40 mills per kWh.

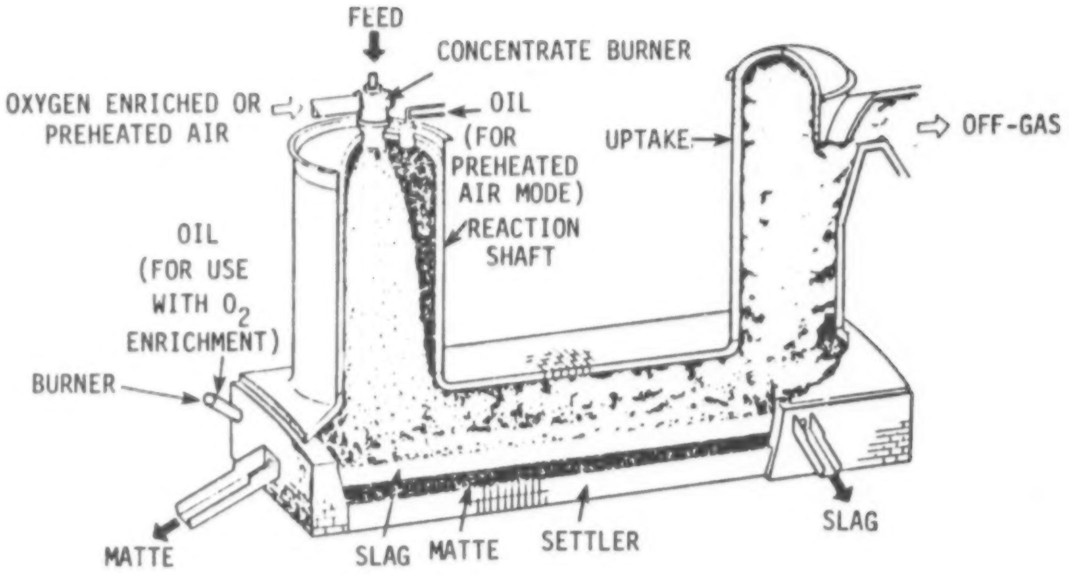
FEED
CONCENTRATE BURNER
OXYGEN ENRICHED OR
PREHEATED AIR
OIL
(FOR
PREHEATED
AIR MODE)
REACTION
SHAFT
UPTAKE
OFF-GAS
OIL
(FOR USE
WITH O_2
ENRICHMENT)
BURNER
MATTE
SLAG
MATTE
SETTLER
SLAG

Figure 16. Outokumpu flash smelting furnace.

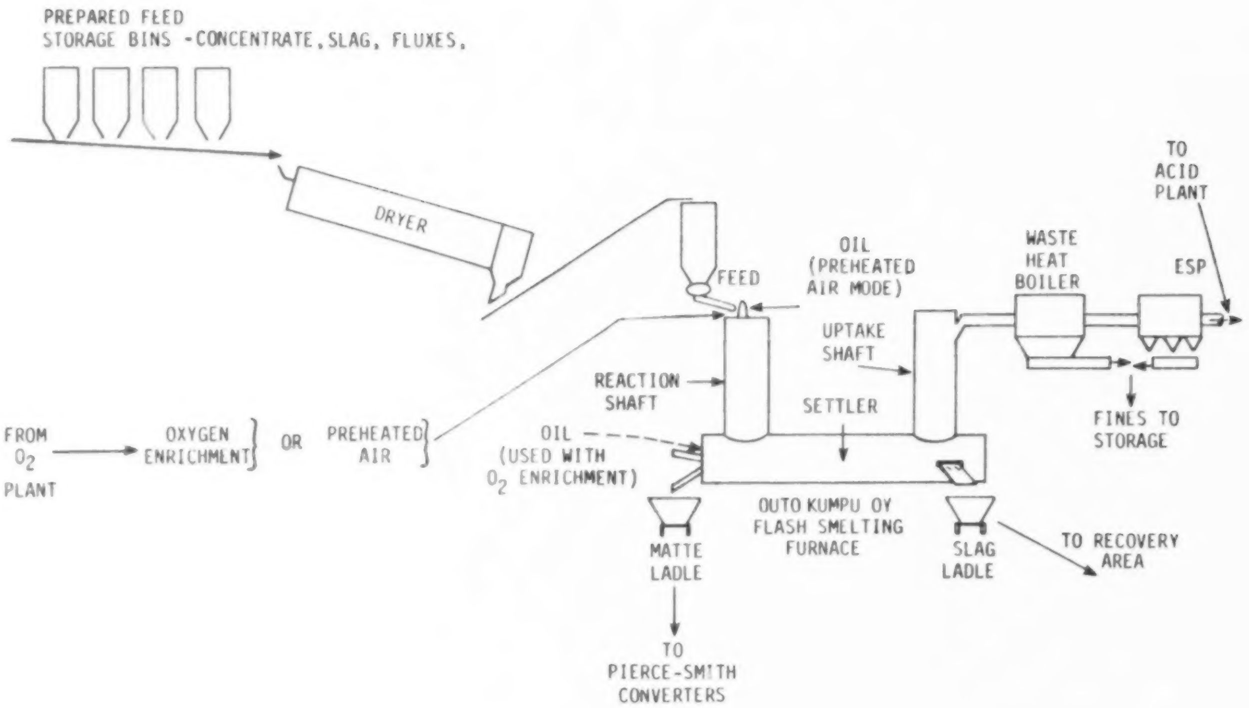
PREPARED FEED
STORAGE BINS -CONCENTRATE, SLAG, FLUXES.
DRYER
FEED
OIL (PREHEATED AIR MODE)
WASTE HEAT BOILER
TO ACID PLANT
ESP
UPTAKE SHAFT
REACTION SHAFT
SETTLER
FINES TO STORAGE
FROM O_2 PLANT
OXYGEN ENRICHMENT
OR
PREHEATED AIR
OIL (USED WITH O_2 ENRICHMENT)
OUTO KUMPU OY FLASH SMELTING FURNACE
MATTE LADLE
SLAG LADLE
TO RECOVERY AREA
TO PIERCE-SMITH CONVERTERS

Figure 17. Process flow for Outokumpu Oy flash-smelting furnace.

Based on the data presented by Kellogg and Henderson,[10] the equivalent energy (for oxygen, fuel, and the acid plant) to produce anode copper is 1.03×10^6 kcal/Mg (3.71×10^6 Btu/ton) of concentrate. This is about 73 percent of the energy used in a smelter with an uncontrolled, wet-charge, conventional reverberatory furnace.

A new smelter (PASAR), which began operation in the Philippines in June 1983, has an Outokumpu Oy furnace with three electrodes inserted between the settler and uptake in the furnace. The PASAR furnace shaft is 6.5 m (21.3 ft) in diameter and 6.9 m (22.6 ft) high. The settler is 20 m (65.6 ft) long by 7 m (22.9 ft) wide, and the uptake is 2.5 m (8.2 ft) in diameter. The three electrodes, which are 2.5 m (8.2 ft) apart, have a capability of 4200 kVa. The plant was built under a turnkey contract by Marubeni Corp., Mitsui Mining and Smelting Co., and Mesco, Inc. (Mitsui Kinzoku Engineering Service).[37]

In 1976, Phelps-Dodge started an Outokumpu Oy flash smelting unit with a production capacity of 136,080 Mg (156,000 tons) of copper per year at their Playas smelter in Tyrone, New Mexico. Sulfur dioxide is controlled by use of a sulfuric acid plant. The copper content in the matte is approximately 60 percent.

If a smelter can use most of the existing facilities and the space now occupied by a reverberatory furnace, the following major process equipment modifications would be required to handle 907.2 Mg (1000 tons) per day of concentrate:

- Installation of rotary or fluid-bed dryer(s), fabric filters, or ESP(s).
- Installation of an oxygen plant somewhere near the existing reverberatory furance area.
- Possible relocation of day bins, fines return, and weighing and handling equipment for all feed components.
- Space for acid plant gas cleaning. If an acid plant already exists, modifications may be necessary for the higher-strength gases. The modifications are similar to those reported for the INCO system.
- Alterations to the existing reverberatory waste-heat boilers, ducting, piping, and structural changes.
- Installation and modifications of control(s) and instrumentation.
- Process scheduling of the Peirce-Smith converters for less blowing time.

Personnel would have to be trained for the new process equipment changes and techniques.

Because of site-specific factors, conversion cost will vary considerably from plant to plant. Table 25 presents a capital cost estimate for installing an Outokumpu Oy Process in a smelter that produces 90,720 Mg (100,000 tons) of blister copper per year. Table 26 presents the annual operating costs.

This process would produce a matte containing 70 to 75 percent copper for subsequent processing in a Peirce-Smith converter(s). The estimated conversion costs in Table 25 show a total cost of about $87,539,600; nearly half of this amount ($42,500,000) is due to the sulfuric acid plant. With steam credit but no credit for sulfuric acid, the total annual operating cost amounts to about $37,998,000 or $0.42/Mg ($0.19/ton) of copper product (without credit for sulfuric acid).

Mitsubishi Process

The Mitsubishi continuous smelting process consists of a smelting furnace, a slag cleaning furnace, and a converting furnace (Figures 18 and 19).[38-41] The feedstock is made up of concentrate ore, flux, fines, reverts, etc., and the product is blister copper. Transfer between furnaces is accomplished by gravity flow.

The feed material (including the flux) is first crushed and screened to 6 mm (0.24 in.) or under, and then dried in a rotary or fluid bed dryer. This material is stored in feed bins above the smelting furnace. Feed is pneumatically transported to the feed pipes and discharged in a pipe within a lance that contains oxygen-enriched air. The lance terminates above the bath, and the reaction of oxygen with the iron and sulfur starts above this bath area. Supplemental burners are located in the furnace roof area. The reaction is controlled to provide a matte grade of 65 percent copper. Because the copper content in the slag is very high, the slag and matte are discharged continuously (by gravity) to the slag cleaning furnace.

Treatment in the slag-cleaning electric furnace yields a slag containing about 0.5 percent copper, which is discarded. The matte is fed (sometimes with flux) to the conversion furnace. Air or oxygen-enriched air supplies the matte with the needed oxygen for the autogenous conversion. The blister copper is directed to a holding furnace and then, as required, to the anode furnace. The converter slag is granulated, dried, and returned to the smelting furnace.

TABLE 25. ESTIMATED CAPITAL COST OF CONVERTING A REVERBERATORY FURNACE PRODUCING 90,720 Mg (100,000 tons[a]) OF BLISTER COPPER PER YEAR TO THE OUTOKUMPU OY PROCESS

Item	Factor	Item	Cost, $
1. Equipment cost - FOB job site Rotary dryer(s), blower(s), fabric filter(s), alteration to storage bins, conveyors, Outokumpu-Oy furnace[b] and ancillaries, hooding feeders, burner(s), ESP(s), waste-heat boiler(s), modifications, ducting, etc.			9,476,400
2. Installed, erected equipment	0.456	1	4,231,200
3. Piping, insulation	0.084	1&2	1,159,000
4. Electrical, instrumentation	0.081	1&2	1,117,600
5. Foundations, painting, miscellaneous items	0.048	1&2	622,300
6. Structural building alterations			187,800
7. Site clearance - remove existing reverb, ductwork			653,400
8. Turnkey - oxygen plant [0.8 kg O_2/kg Cu (0.8 lb O_2/lb Cu)]			9,887,600
9. Turnkey - acid plant 1066 Mg (1175 tons) capacity			42,500,000
10. Miscellaneous - battery limits	0.009	8&9	471,500
11. Equipment costs (installed)			70,442,500
Indirect Costs			
12. Engineering	0.10	1-7,10	1,805,500
13. Startup	0.035	1-7,10	631,900
22. Contractor's fee and offsite	0.05	1-7,10	902,700
23. Contingency	0.25	1-7,10 12,13, 22	5,438,800
24. Interest during construction	0.105	11-13, 22, 23	8,318,200
30. Total indirect costs			17,097,100
31. TOTAL PLANT COSTS			$87,539,600

[a] Ton = 2000 pounds.

[b] One-furnace operation, Outokumpu Oy with oxygen enrichment and reduced Peirce-Smith converter(s) operation.

TABLE 26. ANNUAL OPERATING COSTS OF CONVERTING A REVERBERATORY FURNACE PRODUCING 90,720 Mg (100,000 tons[a]) OF BLISTER COPPER PER YEAR TO THE OUTOKUMPU OY PROCESS

	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					$ per Mg (ton) of copper	$1000/yr
51. Raw materials[b] - lime[c]	0.907 Mg (tons)	8,700 tons	40.00	0.096 (0.087)	3.48	348
56. Direct labor (134 people)	Hours	2,080 h/man	10.00			2,558
57. Supervision	15%	Direct labor				384
58. Maintenance labor	1.875%	Installed cost				1,641
59. Maintenance supervision	20%	Maintenance labor				328
60. Maintenance materials	2%	Installed cost				1,751
61. Operating supplies	20%	Plant maintenance				744
62. Payroll overhead	60%	Labor and supervision				2,947
63. Electricity	kWh	8.292×10^7	0.04	914 (829.2)	36.56 (33.17)	3,317
64. Oil	3.78 liters (gal)	3.19×10^6 gal	1.00	133.1 (31.9)	35.2 (31.9)	3,190
65. Natural gas	28.3 m^3 (1000 ft^3)	31,500 M ft^3d	2.50	0.01 (0.315)	0.87 (0.79)	79
66. Water - process	3,785 liters (1000 gal)	7.42×10^4 M gal	0.34	3.1 (0.742)	0.28 (0.25)	25
67. Water - cooling	3,785 liters (1000 gal)	3.36×10^4 M gal	0.06	1.385 (0.332)	0.022 (0.02)	2
71. Administration and overhead	40%	Labor, supervision, materials, and supplies				2,974
76. Taxes and insurance	2%	Installed cost				1,751
78. Depreciation (straight-line						
Acid and oxygen plant	10.526%	Acid and oxygen plant costs				6,148
Smelting equipment	7.143%	Smelter costs				2,081
79. Cost of funds or interest	10.00%	Total plant cost				8,754
80. Total operating cost[b,d]						39,022
82. Byproduct credit[e] - H_2SO_4	0.907 Mg (tons)	297,000	20.00	3.27 (2.97)	59.40	-5,940
83. Byproduct credit[f] - steam	kWh	2.56×10^7	0.04			-1,024
90. Adjusted total operating costs with acid credit						33,082
91. Adjusted total operating costs with steam credit						37,998
92. Adjusted total operating costs with steam and acid credit						32,058

(continued)

TABLE 26 (continued)

	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					$ per Mg (ton) of copper	$1000/yr
100. Cost per kilogram (pound) of blister copper with steam and acid credit						0.3534 (0.1603)
101. Cost per kilogram (pound) of blister copper with steam credit but no acid credit[b,d]						0.4188 (0.1900)
102. Cost per kilogram (pound) of blister copper with steam and acid neutralization[b,d]						0.4927 (0.2235)

[a] Includes acid plant, oxygen plant, reduced blowing time at Peirce-Smith converters, material handling, gas and dust handling, and standby natural gas for heating (O-S furnace).

[b] Cost of ore or fluxes, land, or sludge disposal not included.

[c] For neutralization of acid plant sludge.

[d] Does not include depreciation and maintenance for Peirce-Smith converters and ancillaries or material handling, but does include steam credit.

[e] Either for sale (F.O.B. the smelter) or credited if utilized within the company or corporation.

[f] Steam generated from waste heat boiler(s), credited at the rate of 14,500 Btu/kWh and 40 mills per kWh.

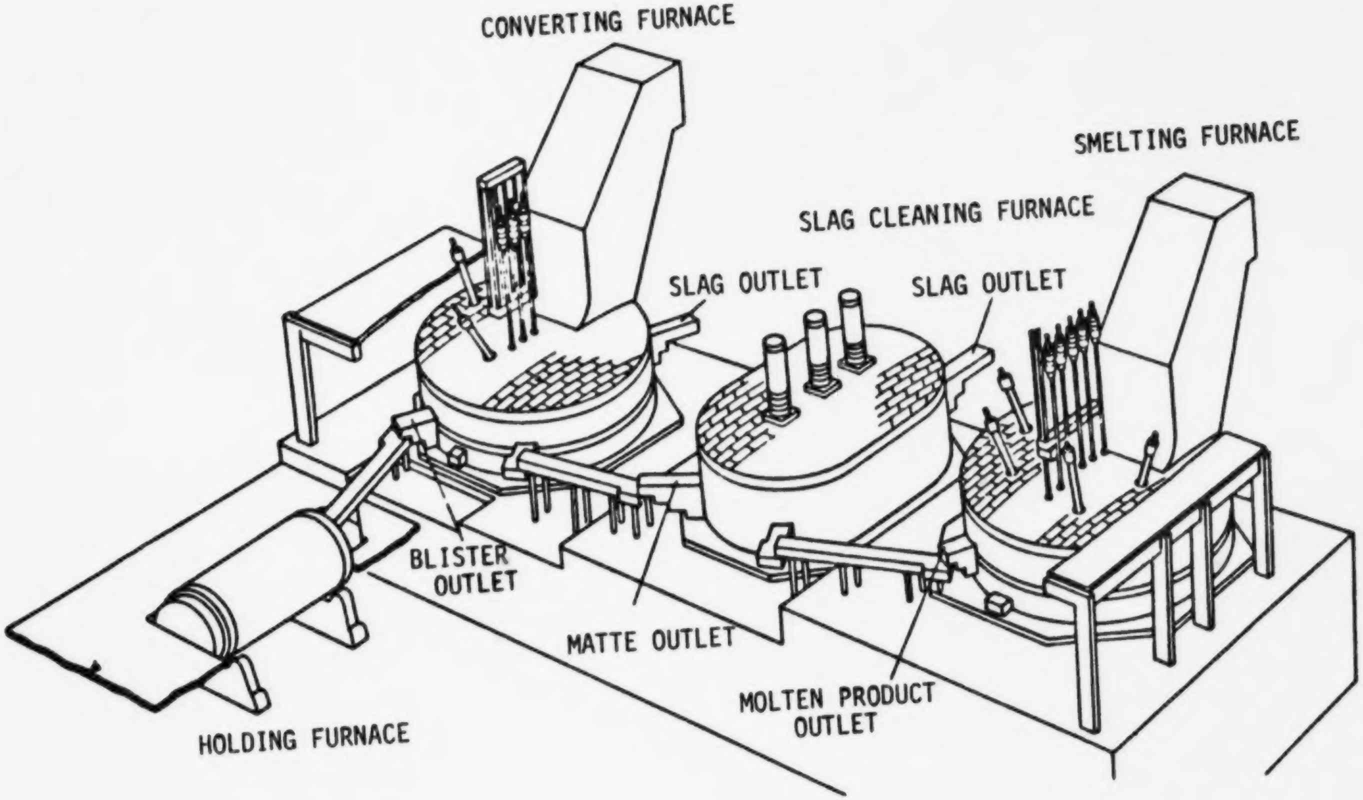
CONVERTING FURNACE
SMELTING FURNACE
SLAG CLEANING FURNACE
SLAG OUTLET
SLAG OUTLET
BLISTER OUTLET
MATTE OUTLET
MOLTEN PRODUCT OUTLET
HOLDING FURNACE

Figure 18. Smelting, slagging and converting, gravity-flow - Mitsubishi Process.

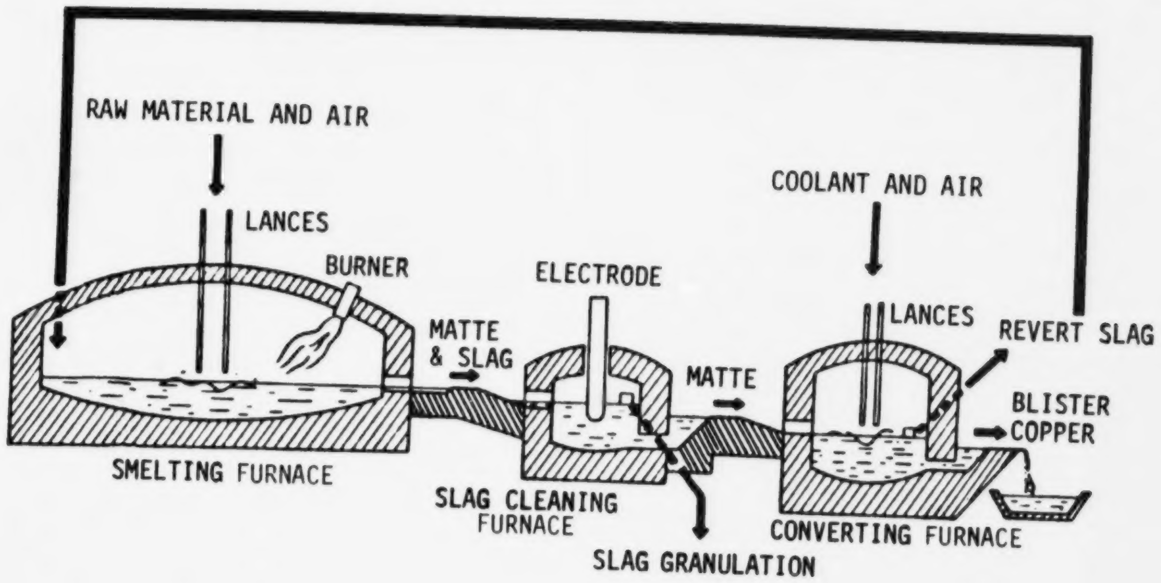
RAW MATERIAL AND AIR
LANCES
BURNER
SMELTING FURNACE
MATTE
& SLAG
ELECTRODE
SLAG CLEANING
FURNACE
SLAG GRANULATION
MATTE
COOLANT AND AIR
LANCES
REVERT SLAG
BLISTER
COPPER
CONVERTING FURNACE

Figure 19. Schematic of gravity-flow Mitsubishi process.

The off-gases from the furnaces are cooled through waste-heat boilers and then sent to an ESP and on to the acid plant. The combined SO_2 strength is approximately 12 percent.

Based on the data presented by Kellogg and Henderson,[10] the equivalent energy required by this process for oxygen, fuel, and the acid plant to produce anode copper is 1.02×10^6 kcal/Mg (4.05×10^6 Btu/ton) of concentrate. This is about 86 percent of the energy required by a smelter using an uncontrolled, wet-charged, conventional, reverberatory furnace.

If a smelter can use existing facilities and the space now occupied by a reverberatory furnace, the following major process equipment modifications would be required to handle 907.2 Mg (1000 tons) per day of concentrate:

- Installation of rotary or fluid-bed dryer(s), fabric filter(s), or ESP(s).
- Installation of an oxygen plant near the existing reverberatory area.
- Possible modifications and relocation of day bins, fines return, and weighing and handling equipment for all feed components.
- Space for gas cleaning and an acid plant. If an acid plant already exists, modifications may be necessary for the higher-strength gases. These modifications are similar to those reported for the INCO system.
- Removal of the reverberatory unit(s) and modifications to the Peirce-Smith converter(s) for use as holding furnace(s), or they may be scrapped.
- Installation and modifications of controls and instrumentation.

Personnel would have to be trained on the new process equipment and techniques.

Because of site-specific factors, conversion costs will vary considerably from plant to plant. Table 27 presents a capital cost estimate for installing the Mitsubishi continuous process in an existing smelter producing 90,720 Mg (100,000 tons) of blister copper per year. These estimated conversion costs show a total cost of about \$77,980,300; about 42 percent of this amount (\$32,580,000) is due to the sulfuric acid plant. As shown in Table 28, the total annual operating costs amount to about \$36,476,000 or \$0.40/Mg (\$0.18/lb) of copper product (with no credit for sulfuric acid, but with steam credit).

TABLE 27. ESTIMATED CAPITAL COST OF CONVERTING A REVERBERATORY FURNACE PRODUCING 90,720 Mg (100,000 tons[a]) OF BLISTER COPPER PER YEAR TO THE CONTINUOUS MITSUBISHI PROCESS FOR BLISTER COPPER

Item	Factor	Item	Cost, $
1. Equipment cost - FOB job site			
Rotary dryers, blowers, fabric filters, alteration to storage bins, conveyors, 2 sets of furnaces[b] and ancillaries, hooding, feeders, burners, ESP(s), waste-heat boilers, modifications, ducting, etc.			9,991,000
2. Installed, erected equipment	0.456	1	4,555,900
3. Piping, insulation	0.084	1&2	1,192,800
4. Electrical, instrumentation	0.081	1&2	1,207,400
5. Foundations, painting, miscellaneous items	0.048	1&2	712,800
6. Structural building alterations			187,800
7. Site clearance - remove existing reverb, ductwork			700,000
8. Turnkey - oxygen plant [0.8 kg/kg Cu (0.8 lb/lb Cu]			9,887,600
9. Turnkey - acid plant 1066-Mg (1175-ton) capacity			32,580,000
10. Miscellaneous - battery limits	0.009	8&9	424,700
11. Equipment costs (installed)			61,440,000
Indirect Costs			
12. Engineering	0.10	1-7,10	1,897,200
13. Startup	0.035	1-7,10	664,000
22. Contractor's fee and offsite	0.05	1-7,10	948,600
23. Contingency	0.25	1-7,10, 12,13, 22	5,620,600
24. Interest during construction	0.105	11-13,	7,409,900
30. Total indirect costs		22, 23	16,540,300
31. TOTAL PLANT COSTS			$77,980,300

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[a] Ton = 2000 pounds.

[b] Two sets of Mitsubishi furnaces and holding furnaces, but no Peirce-Smith converters.

TABLE 28. ANNUAL OPERATING COSTS OF CONVERTING A REVERBERATORY FURNACE PRODUCING 90,720 Mg (100,000 tons[a]) OF BLISTER COPPER PER YEAR TO THE CONTINUOUS MITSUBISHI PROCESS

	Unit	Units/yr	\$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					\$ per Mg (ton) of copper	\$1000/yr
51. Raw materials[b] - lime[c]	0.907 Mg (tons)	8,850 tons	40.00	0.0885	3.54	354
56. Direct labor[a]	Hours	2,080 h/man	10.00			2,870
57. Supervision	15%	Direct labor				431
58. Maintenance labor	1.875%	Installed cost				1,462
59. Maintenance supervision	20%	Maintenance labor				292
60. Maintenance materials	2%	Installed cost				1,560
61. Operating supplies	20%	Plant maintenance				663
62. Payroll overhead	60%	Labor and supervision				3,033
63. Electricity	kWh	802.4 x 10^5	0.04	.884.5 (802.4)	35.38 (32.10)	3,210
64. Coal and oil	0.907 Mg (tons) 3.78 liters (gal)	1,500 4.593 x 10^6 gal	45.00 1.00	0.0165 (0.015) 191.6 (45.93)	0.75 (0.68) 50.63 (45.93)	68 4,593
65. Natural gas	28.3 m³ (1000 ft³)	12,100 M ft³	2.50	0.003 (0.121)	0.33 (0.30)	30
66. Water - process	3,785 liters (1000 gal)	7.82 x 10^4 M gal	0.34	3.26 (0.782)	0.29 (0.26)	26
67. Water - cooling	3,785 liters (1000 gal)	6.28 x 10^4 M gal	0.06	2.62 (0.628)	0.044 (0.04)	4
71. Administration and overhead	40%	Labor, supervision, materials, and supplies				2,911
76. Taxes and insurance	2%	Installed cost				1,560
78. Depreciation (straight-line)						
Acid and oxygen plant	10.526%	Acid and oxygen plant related costs				4,989
Smelting equipment	7.143%	Smelter related costs				2,185
79. Cost of funds or interest	10.00%	Total installed cost				7,798
80. Total operating cost[b,d]						38,039
82. Byproduct credit[e] - H_2SO_4	0.907 Mg (tons)	318,000	20.00	3.18	63.60	-6,360
83. Byproduct credit[f] - steam	lb					-1,563
90. Adjusted total operating costs with acid credit						31,679
91. Adjusted total operating costs with steam credit						36,476

(continued)

TABLE 28 (continued)

	Unit	Units/yr	$/unit	Units per basic unit of Cu, Mg (tons)	Total costs	
					$ per Mg (ton) of copper	$1000/yr
92. Adjusted total operating costs with steam and acid credit						30,116
100. Cost per kilogram (pound) of blister copper with steam and acid credit						0.3320 (0.1506)
101. Cost per kilogram (pound) of blister copper with steam credit but no acid credit[b,d]						0.4021 (0.1824)
102. Cost per kilogram (pound) of blister copper with steam credit and acid neutralization[b,d]						0.4759 (0.2159)

[a] Includes acid plant, oxygen plant, holding furnace in lieu of converters, material handling, gas and dust handling, and standby natural gas for heating [(Mitsubishi furnaces, holding furnaces, launders (gravity)].

[b] Cost of ore or fluxes, land, or sludge disposal not included.

[c] For neutralization of acid plant sludge.

[d] Does not include depreciation and maintenance for ancillaries or material handling.

[e] Either for sale (F.O.B. the smelter) or credited if utilized within the company or corporation.

[f] Steam generated from waste heat boiler(s), credited at the rate of 14,500 Btu/kWh and 40 mills per kWh.

SECTION 3

CONTROL OF WEAK SO_2 STREAMS

For weak gas streams (i.e., those containing less than about 3.5 percent SO_2), flue gas scrubbing can be considered for reducing the SO_2 emissions. In this process, the gases are contacted with an absorbent medium in an absorber or a scrubber vessel, where the SO_2 reacts with the absorbent or is dissolved in the solution.

The two basic categories of flue gas scrubbing (FGS) processes are regenerable and nonregenerable. This classification is based on whether the absorbent is regenerated for reuse by separating the sulfur compounds from the absorbent and recovering them as a byproduct, or whether the spent absorbent is converted to a gypsum byproduct or discarded as waste. Regenerable processes require additional steps to convert the sulfur compounds into byproducts such as liquid sulfur dioxide, sulfuric acid, or elemental sulfur.

Four types of FGS systems are described. Two of them have been used successfully on smelters in Japan. These are the lime (nonregenerable) and the magnesium oxide (regenerable) scrubbing systems. The other two systems discussed here are the limestone and the citrate processes. The limestone process falls into the nonregenerable category, and the citrate process is a regenerable system that has been piloted on smelters in Sweden (by Flakt at Boliden) and in the United States (by the Bureau of Mines).

Each scrubbing system is based on a gas stream that has passed through a waste-heat boiler and an electrostatic precipitator (ESP). Figure 20 presents a generalized scrubber system flow diagram showing the gas pretreatment options and the gas/liquid system. If the gas stream is above 205°C (400°F) after it has passed through the ESP, it can be treated in a spray chamber [to reduce the temperature to approximately 53°C (127°F)]. If the temperature is already below 205°C (400°F), the gas stream can go directly to the absorber. If particulates also are to be removed, the stream can be sent to a venturi scrubber or combinations of the above. The cooled gas then goes to the absorber. Ducting to bypass a portion of the gas stream (or all of it) in an emergency can also be included.

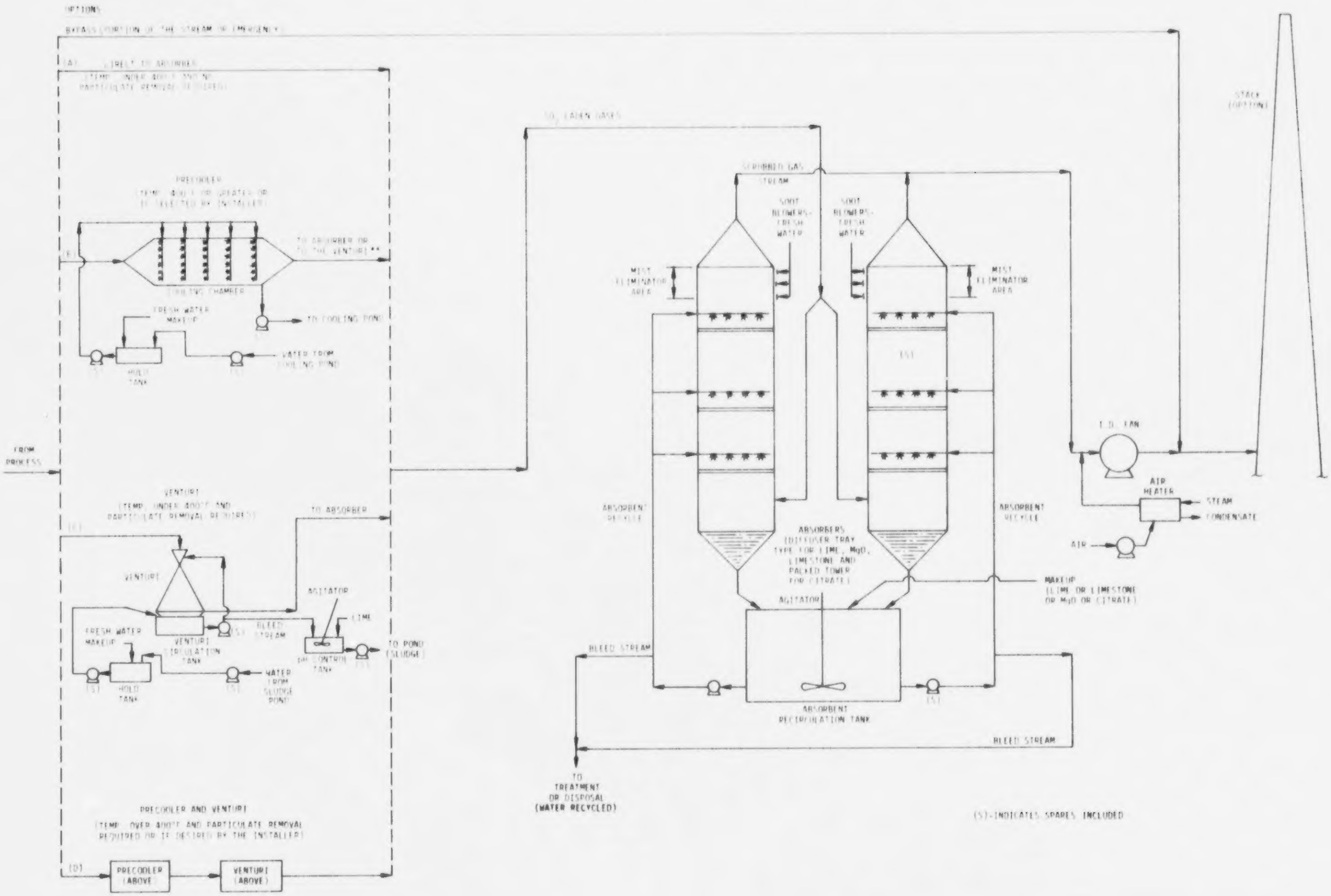

OPTIONS
BYPASS (PORTION OF THE STREAM OR EMERGENCY)
(A) DIRECT TO ABSORBER
(TEMP. UNDER 400°F AND NO PARTICULATE REMOVAL REQUIRED)
PRECOOLER
(TEMP. 400°F OR GREATER OR IF SELECTED BY INSTALLER)
(B)
TO ABSORBER OR TO THE VENTURI**
COOLING CHAMBER
FRESH WATER MAKEUP
TO COOLING POND
(S)
HOLD TANK
WATER FROM COOLING POND
FROM PROCESS
VENTURI
(TEMP. UNDER 400°F AND PARTICULATE REMOVAL REQUIRED)
(C)
TO ABSORBER
VENTURI
AGITATOR
LIME
FRESH WATER MAKEUP
VENTURI CIRCULATION TANK
BLEED STREAM
pH CONTROL TANK
TO POND (SLUDGE)
HOLD TANK
WATER FROM SLUDGE POND
PRECOOLER AND VENTURI
(TEMP. OVER 400°F AND PARTICULATE REMOVAL REQUIRED OR IF DESIRED BY THE INSTALLER)
(D)
PRECOOLER (ABOVE)
VENTURI (ABOVE)
SO_2 LADEN GASES
SCRUBBED GAS STREAM
SOOT BLOWERS-FRESH WATER
SOOT BLOWERS-FRESH WATER
MIST ELIMINATOR AREA
MIST ELIMINATOR AREA
ABSORBENT RECYCLE
ABSORBENT RECYCLE
ABSORBERS (DIFFUSER TRAY TYPE FOR LIME, MgO, LIMESTONE AND PACKED TOWER FOR CITRATE)
AGITATOR
MAKEUP (LIME OR LIMESTONE OR MgO OR CITRATE)
BLEED STREAM
ABSORBENT RECIRCULATION TANK
BLEED STREAM
TO TREATMENT OR DISPOSAL (WATER RECYCLED)
(S)-INDICATES SPARES INCLUDED
I.D. FAN
AIR HEATER
STEAM
CONDENSATE
AIR
STACK (OPTION)

Figure 20. Generalized scrubbing system for SO_2 removal.

Capital and annual operating costs for each FGS system are also presented. These costs are generated by a method similar to that used in "A Standard Procedure for Cost Analysis of Pollution Control Operations."[42] The costs generated reflect a "study estimate" with a reliability of ±30 percent. A computer-aided cost estimating technique (described in Appendix B) was used to generate these costs. Capital costs consist of direct equipment costs; installation and construction costs; ponding; and indirect costs of construction, engineering, overhead, contractor's fee, interest during construction, and contingency.

Annual operating costs include raw materials, utilities, labor, maintenance, overhead, and fixed costs of depreciation (straight-line), insurance, taxes, and the cost of capital.

Costs for an FGS system will vary widely depending on the gas pretreatment required and the sludge treatment and disposal alternatives selected. The necessity for bypass ducting, a new stack, sludge pond, etc., will also affect the capital cost. The computer-aided cost estimating system allows the user to select input parameters for a specific case.

LIME-BASED FLUE GAS SCRUBBING SYSTEM

The lime process is a wet, nonregenerable SO_2 absorption process in which an alkaline slurry formed from the lime is circulated through a scrubber/absorber tower, where it reacts with SO_2 in the flue gas. Calcium sulfite and sulfate formed by the reaction are then separated in clarifiers, filters, etc. The sludge produced by the system can be oxidized to produce an inert landfill material (gypsum), or it can be stored in sludge ponds equipped with adequate barriers to prevent contamination of surface or ground waters.

Lime FGS systems have demonstrated the ability to remove in excess of 90 percent of the inlet SO_2 at several utility boiler installations. Basically, the following reactions take place:

Lime reagent slurry: $CaO + H_2O \rightarrow Ca(OH)_2$

Absorber: $2SO_2 + 2Ca(OH)_2 \rightarrow CaSO_3 \cdot x\ H_2O + CaSO_4 \cdot H_2O$

Oxidation (gypsum): $y\ O_2 + 2CaSO_3 \cdot x\ H_2O \rightarrow 2CaSO_4 \cdot 2H_2O + z\ H_2O$

Process Description

As Figure 20 shows, SO_2-laden gases discharged directly from the smelting process(es), or passed through the precooler (or venturi when particulates are to be removed from the gas stream), enter the absorption tower near the base. As the gases pass up through the tower, they are sprayed countercurrently with the lime slurry absorbent at a rate of about 4.0 liters/m³ (30 gal/1000 acfm). The lime slurry is initially prepared by reacting lime (CaO) with fresh water in a slaker, as shown in Figure 21. The calcium hydroxide product [$Ca(OH)_2$] from the slaker, which contains about 40 percent solids, is diluted with recycled water to approximately 10 percent solids by weight. This dilute lime solution is pumped to the absorber recirculation tank, where it mixes with the recycled absorbent from the absorber. Approximately 10 percent excess lime is fed to the system on a stoichiometric basis. With adequate contact time and area for the intimate mixing of SO_2 and slurry, SO_2 removal efficiencies of approximately 90 percent can be achieved. The scrubbed gas stream leaving the absorber passes through a mist eliminator and an induced-draft fan before entering the stack. The mist eliminator captures entrained droplets and returns them to the circulating absorbent. Heated air may be mixed with the main gas stream to raise its temperature approximately 28°C (50°F) to minimize dew point problems and enhance dispersion. The hot air stream is provided by blowing ambient air through a heater, as shown in Figure 20.

The liquid stream leaving the base of the absorber contains approximately 10 percent solids consisting primarily of calcium sulfite/bisulfite and some calcium sulfate. Some unreacted lime is also present. This liquid stream enters a recirculation tank, where it is mixed with the fresh makeup lime solution and then pumped back through the absorber.

To minimize buildup of calcium sulfite ($CaSO_3$), calcium sulfate ($CaSO_4$), and impurities in the absorption system, a bleed or purge stream is taken from the recirculation tank. As Figure 22 shows, this bleed stream can be handled in several ways, depending on whether the purged compounds are desired in a sludge form or solid form. About 7 or 8 percent of the liquid stream from the absorber recirculation tank is bled off. The bleed stream can be directed 1) to the pond, 2) to the thickener, 3) through the thickener and a vacuum filter or a centrifuge, or 4) to an oxidation system. The bleed stream in three of the four disposal systems is sent to a thickener. The overflow, a liquid with less than 1 percent solids, is sent to a holding tank for recycled water. When the oxidation process is used, the underflow (approximately 20 percent solids) is pumped to multiple centrifuges or a vacuum filter to produce a gypsum cake with an 80 percent solids content. When a thickener/vacuum filter or thickener/centrifuge is used without oxidation, the solids contents of the discharge is 60 percent. These solid wastes are trucked to a landfill or disposal pond.

Water losses requiring makeup consist of water lost in the flue gas and water lost in the sludge and/or gypsum systems, both

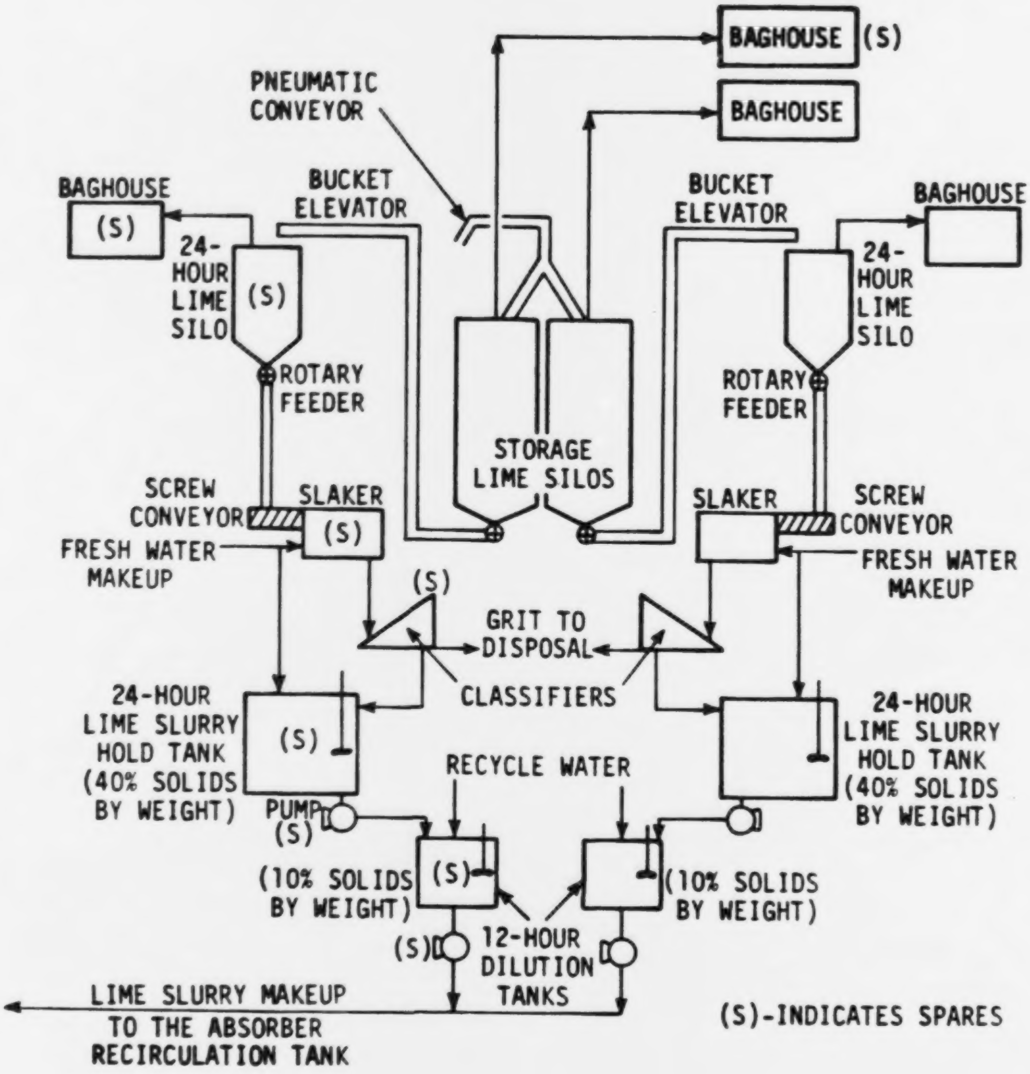
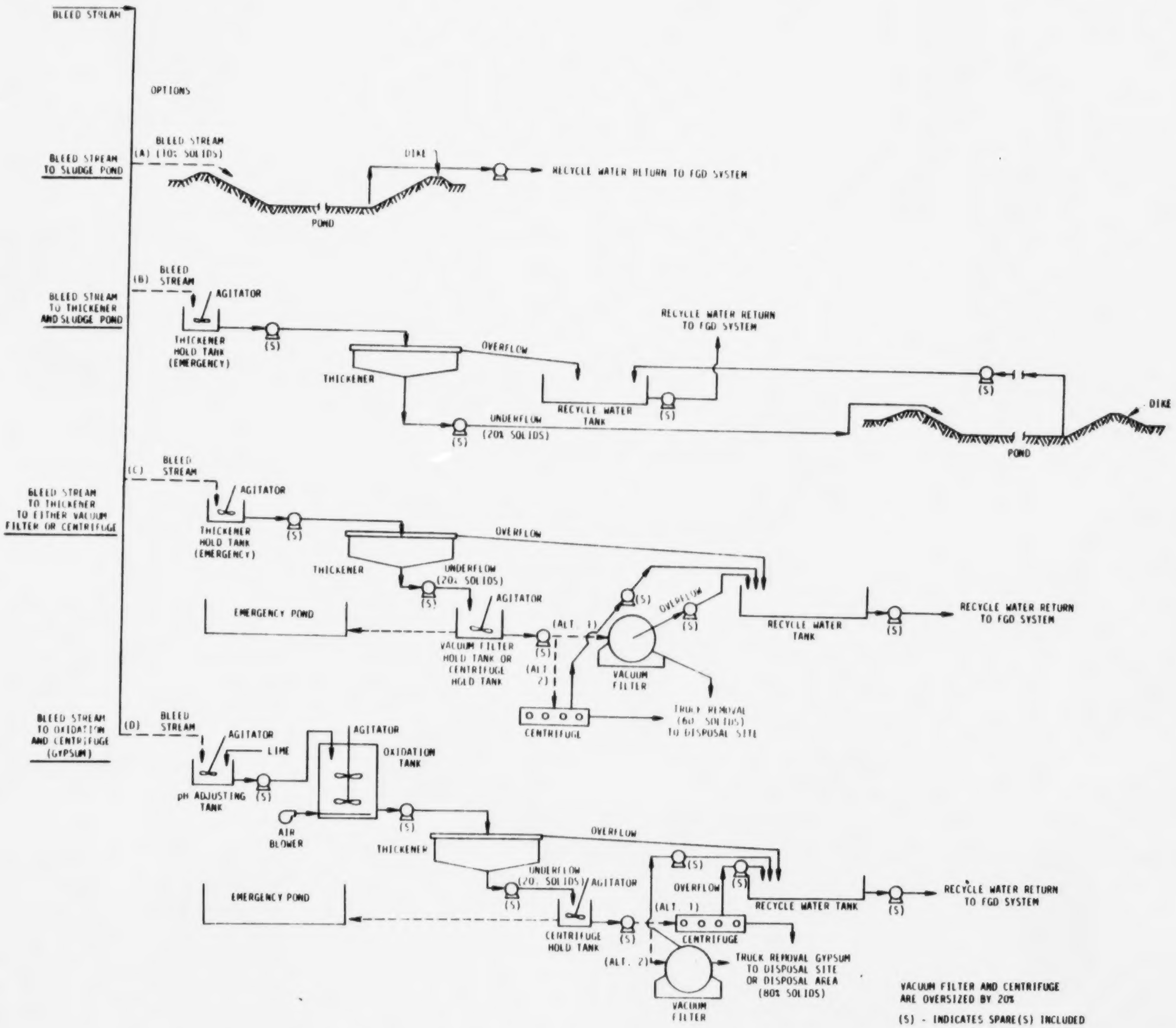

BAGHOUSE (S)
PNEUMATIC CONVEYOR
BAGHOUSE
BAGHOUSE
(S)
BUCKET ELEVATOR
BUCKET ELEVATOR
BAGHOUSE
24-HOUR LIME SILO
(S)
24-HOUR LIME SILO
ROTARY FEEDER
ROTARY FEEDER
STORAGE LIME SILOS
SCREW CONVEYOR
SLAKER
(S)
SLAKER
SCREW CONVEYOR
FRESH WATER MAKEUP
FRESH WATER MAKEUP
(S)
GRIT TO DISPOSAL
CLASSIFIERS
24-HOUR LIME SLURRY HOLD TANK (40% SOLIDS BY WEIGHT)
(S)
24-HOUR LIME SLURRY HOLD TANK (40% SOLIDS BY WEIGHT)
RECYCLE WATER
PUMP (S)
(10% SOLIDS BY WEIGHT)
(S)
(10% SOLIDS BY WEIGHT)
(S)
12-HOUR DILUTION TANKS
LIME SLURRY MAKEUP TO THE ABSORBER RECIRCULATION TANK
(S)-INDICATES SPARES

Figure 21. Schematic of the lime slurry makeup and storage systems.


BLEED STREAM
OPTIONS
BLEED STREAM TO SLUDGE POND
(A) BLEED STREAM (10% SOLIDS)
DIKE
POND
RECYCLE WATER RETURN TO FGD SYSTEM
BLEED STREAM TO THICKENER AND SLUDGE POND
(B) BLEED STREAM
AGITATOR
THICKENER HOLD TANK (EMERGENCY)
(S)
THICKENER
OVERFLOW
RECYCLE WATER RETURN TO FGD SYSTEM
RECYCLE WATER TANK
UNDERFLOW (20% SOLIDS)
POND
DIKE
BLEED STREAM TO THICKENER TO EITHER VACUUM FILTER OR CENTRIFUGE
(C) BLEED STREAM
AGITATOR
THICKENER HOLD TANK (EMERGENCY)
THICKENER
OVERFLOW
UNDERFLOW (20% SOLIDS)
AGITATOR
EMERGENCY POND
VACUUM FILTER HOLD TANK OR CENTRIFUGE HOLD TANK
(ALT. 1)
(ALT. 2)
VACUUM FILTER
OVERFLOW
RECYCLE WATER TANK
RECYCLE WATER RETURN TO FGD SYSTEM
CENTRIFUGE
TRUCK REMOVAL (60% SOLIDS) TO DISPOSAL SITE
BLEED STREAM TO OXIDATION AND CENTRIFUGE (GYPSUM)
(D) BLEED STREAM
AGITATOR
LIME
pH ADJUSTING TANK
AGITATOR
OXIDATION TANK
AIR BLOWER
THICKENER
OVERFLOW
UNDERFLOW (20% SOLIDS)
AGITATOR
EMERGENCY POND
CENTRIFUGE HOLD TANK
(ALT. 1)
(ALT. 2)
OVERFLOW
CENTRIFUGE
VACUUM FILTER
RECYCLE WATER TANK
RECYCLE WATER RETURN TO FGD SYSTEM
TRUCK REMOVAL GYPSUM TO DISPOSAL SITE OR DISPOSAL AREA (80% SOLIDS)

VACUUM FILTER AND CENTRIFUGE ARE OVERSIZED BY 20%

(S) - INDICATES SPARE(S) INCLUDED

Figure 22. Options for the handling of the scrubber bleed system.

as water of hydration and as free water. Water enters the system as slaker feed water, pump seal water, precooler (when used) water, and mist eliminator wash water. Water from the disposal pond is recirculated.

System Costs

Capital and annual operating costs for a lime-based FGS system with a collection efficiency of 90 percent are shown in Figures 23 and 24 respectively for gas streams containing 1 to 3.5 percent SO_2. In this example, the stack gas at 600°F is first passed through a pre-cooler and venturi scrubber to cool the gas and remove particulate. The sludge is oxidized by blowing air through it and dewatered in a thickener/vacuum filter system before disposal. These data show that capital costs range from about \$3,500 to \$12,360 per m^3/min (\$100 to \$350 per scfm). (Costs are expressed in January 1983 dollars - C.E. Plant Index = 315.5.) A breakdown of the capital costs presented in Table 29 for a 1 percent and 3.5 percent SO_2 stream shows that the SO_2 absorber system is the largest single cost item. This system consists mainly of the absorber vessel, pumps, tanks, and fans. The annual operating costs range from \$2050 to \$6890 per m^3/min (\$58 to \$195 per scfm). Table 30 presents a breakdown of the annual operating costs for a limestone system operating on a 1 percent SO_2 stream. At \$55/Mg (\$50/ton), lime is the major direct operating cost. Fixed costs, including depreciation and interest, amount to about one-third to one-half of the annual operating costs. There is no direct relationship between off-gas flow and copper production; however, an FGS system serving a reverberatory furnace with an equivalent copper throughput* of 90,720 Mg (100,000 tons) per year would cost about \$19,200,000, and annual operating costs would be about \$8,800,000 or \$0.097/kg (\$0.044/lb) of copper produced for control of the reverberatory furnace gas only. This cost must be added to the smelting cost.

LIMESTONE-BASED FLUE GAS SCRUBBING SYSTEM

The limestone-based FGS system is very similar to the lime system. The only differences of any significance are in the preparation of the absorbent (shown in Figure 25 and described here) and the SO_2 removal efficiency (85% compared with 90% for the lime system). Basically, the following reactions take place:

Limestone reagent slurry: $CaCO_3 + H_2O \rightarrow CaCO_3(aq)$

Absorber: $2SO_2 + 2CaCO_3(aq) \rightarrow CaSO_3 \cdot x\ H_2O + CaSO_4 \cdot x_i\ H_2O + H_2CO_3$

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* 2830 m^3/min (100,000 scfm at 1 percent SO_2).

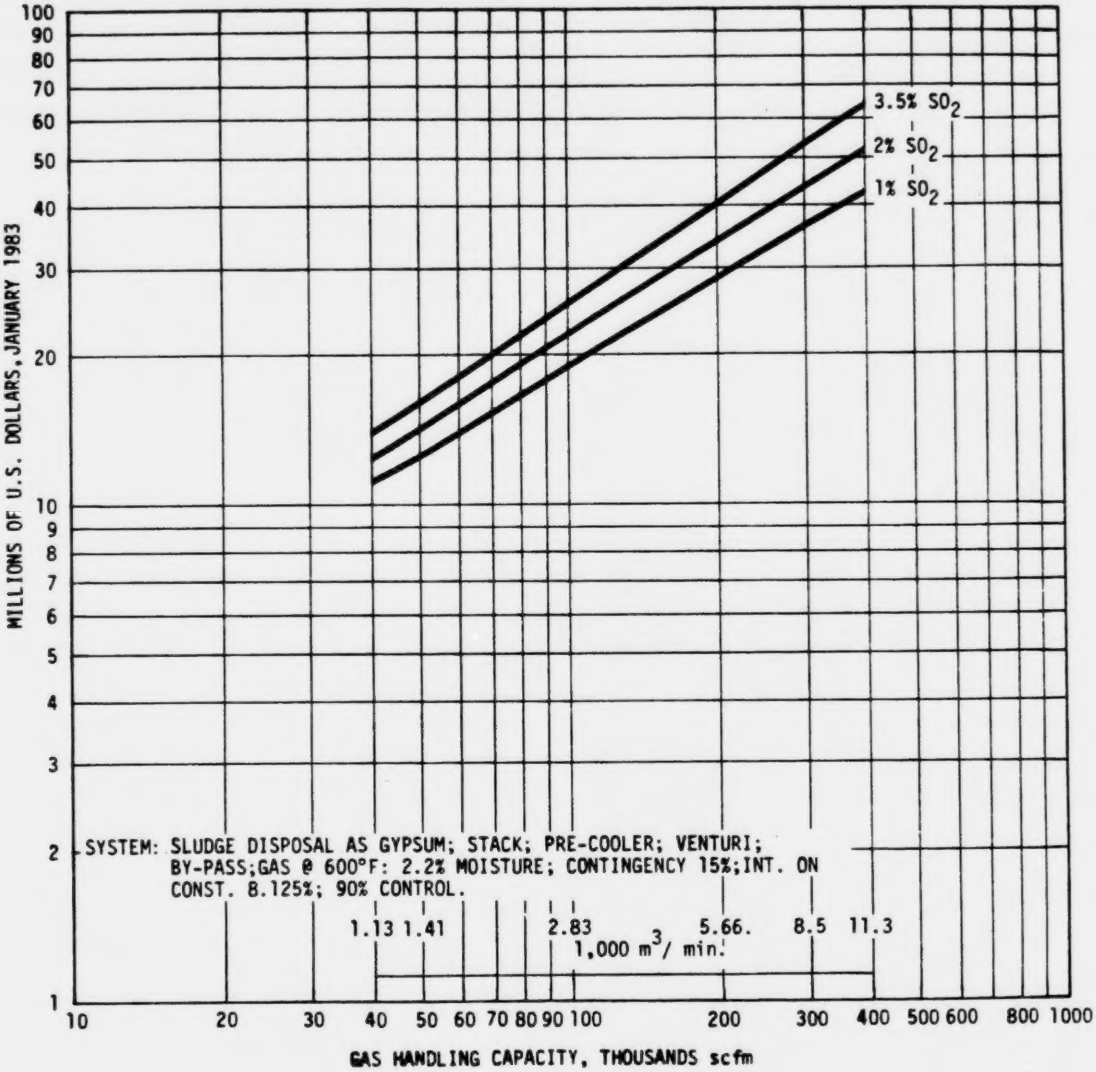
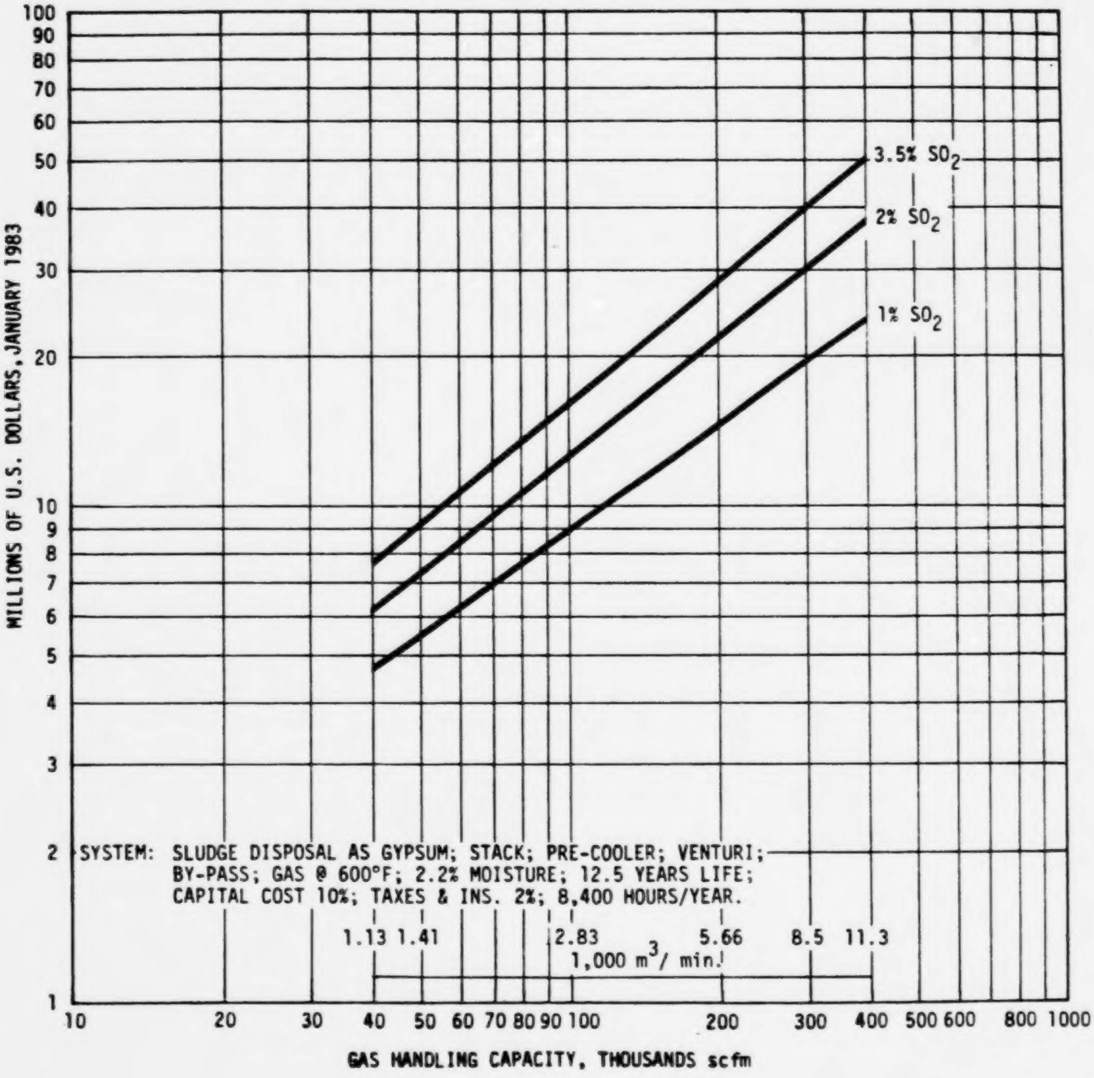


Figure 23. Capital cost of a lime scrubbing FGS system.



SYSTEM: SLUDGE DISPOSAL AS GYPSUM; STACK; PRE-COOLER; VENTURI; BY-PASS; GAS @ 600°F; 2.2% MOISTURE; 12.5 YEARS LIFE; CAPITAL COST 10%; TAXES & INS. 2%; 8,400 HOURS/YEAR.

Figure 24. Annual operating costs of a lime scrubbing FGS system.

TABLE 29. ESTIMATED CAPITAL COST OF A LIME-BASED FGS SYSTEM [2830 m^3/min (100,000 scfm) of flue gas)

Item		Installed costs, $	
		For 1% SO_2	For 3.5% SO_2
1	Materials handling	1,155,500	3,236,500
2	Feed preparation	527,300	851,800
3	Pre-cooler	1,036,200	1,037,100
4	SO_2 scrubbing/venturi	4,702,800	4,702,800
5	Reheat and stack	2,429,600	2,429,600
6	Solids disposal	1,202,400	2,000,500
	Sub-total	11,053,800	14,258,300
7	Disposal pond	70,700	70,700
8	Cooling pond	638,900	646,800
	Total direct cost	11,763,400	14,975,800
		Indirect costs, $	
9	Indirects (31.25% of direct)	3,676,100	4,679,800
10	Interest during construction at 10% for 2.5 years	1,254,500	1,597,000
11	Contingency (15% of Items 1-6, 9, and 10)	2,504,100	3,187,800
	Indirects total	7,434,700	9,464,600
	Total capital costs	19,198,100	24,440,400
	Cooling pond liner cost	475,900	481,800

TABLE 30. ANNUAL OPERATING COSTS OF A LIME-BASED FGS SYSTEM
[2830 m^3/min (100,000 scfm) 1% SO_2]

	Quantity		Unit cost	Annual cost, $
Raw materials				
Lime	4.33 Mg/h (4.78 tons/h)	8400 h/yr	$55.13/Mg ($50.00/ton)	2,007,200
Fixation chemicals	0.066 Mg/h (0.06 ton/h)	8400 h/yr	$55.13/Mg ($50.00/ton)	23,400
Utilities				
Water	651 liters/min (172 gpm)	8400 h/yr	$0.09/1000 liters ($0.35/1000 gal)	30,400
Electricity	1438 kW	8400 h/yr	$0.04/kWh	483,100
Operating labor				
Direct labor	5 men/shift		$9.60/man-hour	420,900
Supervision	15% of direct labor			63,100
Maintenance				
Labor and materials	4% of capital cost			767,900
Supplies	15% of labor and materials			115,200
Overhead				
Plant	50% of operation and maintenance			683,600
Payroll	20% of operating labor			96,800
Fixed costs				
Depreciation	(8.0%)			
Taxes and insurance	(2.3%)			
Capital cost	(10.0%)			
	Sum = 20.3% of fixed investment			3,897,200
Trucking costs	$2.13/m³ ($2.785/yd³)			177,800
	Total annual cost			8,766,600

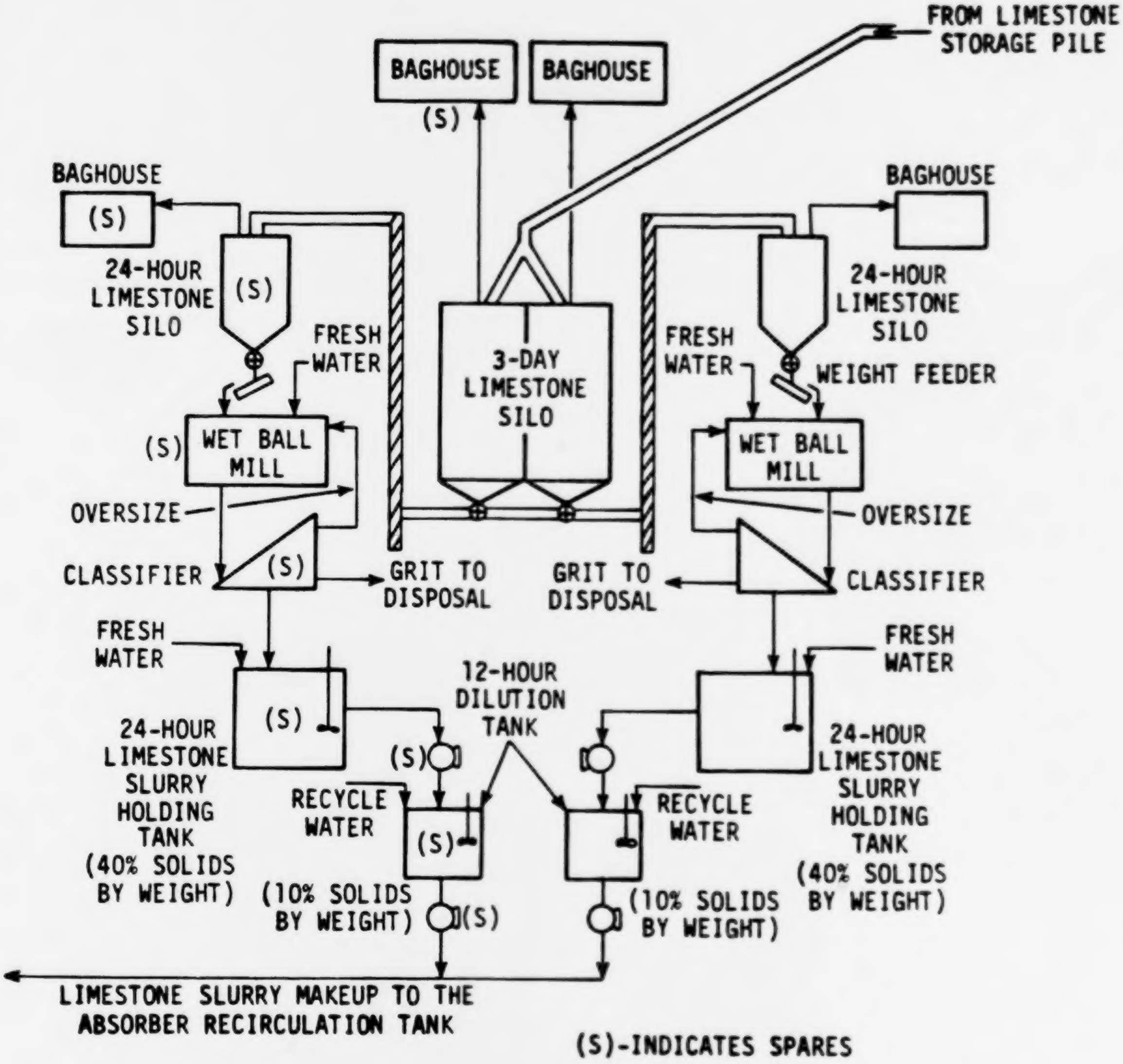

FROM LIMESTONE STORAGE PILE
BAGHOUSE
(S)
BAGHOUSE
BAGHOUSE
(S)
BAGHOUSE
24-HOUR LIMESTONE SILO
(S)
24-HOUR LIMESTONE SILO
FRESH WATER
3-DAY LIMESTONE SILO
FRESH WATER
WEIGHT FEEDER
(S)
WET BALL MILL
WET BALL MILL
OVERSIZE
OVERSIZE
CLASSIFIER
(S)
GRIT TO DISPOSAL
GRIT TO DISPOSAL
CLASSIFIER
FRESH WATER
FRESH WATER
(S)
12-HOUR DILUTION TANK
24-HOUR LIMESTONE SLURRY HOLDING TANK (40% SOLIDS BY WEIGHT)
(S)
RECYCLE WATER
(S)
RECYCLE WATER
24-HOUR LIMESTONE SLURRY HOLDING TANK (40% SOLIDS BY WEIGHT)
(10% SOLIDS BY WEIGHT)
(S)
(10% SOLIDS BY WEIGHT)
LIMESTONE SLURRY MAKEUP TO THE ABSORBER RECIRCULATION TANK
(S)-INDICATES SPARES

Figure 25. Schematic of the limestone slurry makeup and storage systems.

Oxidation (gypsum): $\approx \; y\,O_2 + 2CaSO_3 \cdot x_iH_2O \rightarrow 2CaSO_4 \cdot 2H_2O$
$+ z\,H_2O$

Process Description

Limestone is brought to the storage area at the plant by truck or train. The limestone storage pile should be maintained at a level capable of supplying the plant for 30 to 90 days. From the storage pile the limestone is fed onto a conveyor that leads first to a 3-day silo and then to 24-hour silos. Limestone from the 24-hour silos goes through a weigh feeder to a wet ball mill, which usually reduces it to minus 200 mesh. The limestone slurry reaction requires the dissolution of $CaCO_3$, which is a slower reaction than the dissolution of CaO in the lime process. The rate of reaction is directly related to the particle surface area and therefore to the particle size.

The limestone slurry (about 40 percent solids) is pumped first to a day tank and then to a dilution tank, where recycled water is added to dilute the slurry to approximately 10 percent solids. This makeup slurry is pumped to the absorber recirculation tank, as shown in Figure 20, at a rate of about 8.0 liters/m^3 (60 gal/1000 acfm). A stoichiometric ratio of 1.4 (calcium to sulfur) is used.

The limestone system, like the lime system, uses a recirculating system with a 7 to 8 percent bleed. Fresh water (or recycled water) is added to the system at the ball mill during grinding. Fresh water is also added as pump seal water and as mist eliminator wash water. As previously shown in Figures 20 and 22, the bleed stream from the absorber recirculation line goes to the disposal area in a manner similar to that in the lime system. Figure 22 shows the different sludge disposal treatment systems that can be selected.

System Costs

Figures 26 and 27 show the capital and annual operating costs for a limestone-based FGS system for a gas stream containing 1 to 3.5 percent SO_2 and generating at an 85 percent SO_2 control efficiency. These costs include a pre-cooler and a venturi scrubber to cool and clean the gas stream. The sludge is oxidized, converted to gypsum, and dewatered in a thickener/vacuum filter system before disposal.

The data show that capital costs range from about \$4,592 to \$14,129 per m^3 (\$130 to \$400 per scfm). These costs are higher than the lime-based system primarily because of the larger amount of reagent that must be handled (1:4 calcium to sulfur stoichiometric ratio for limestone compared with a 1:1 ratio for lime).

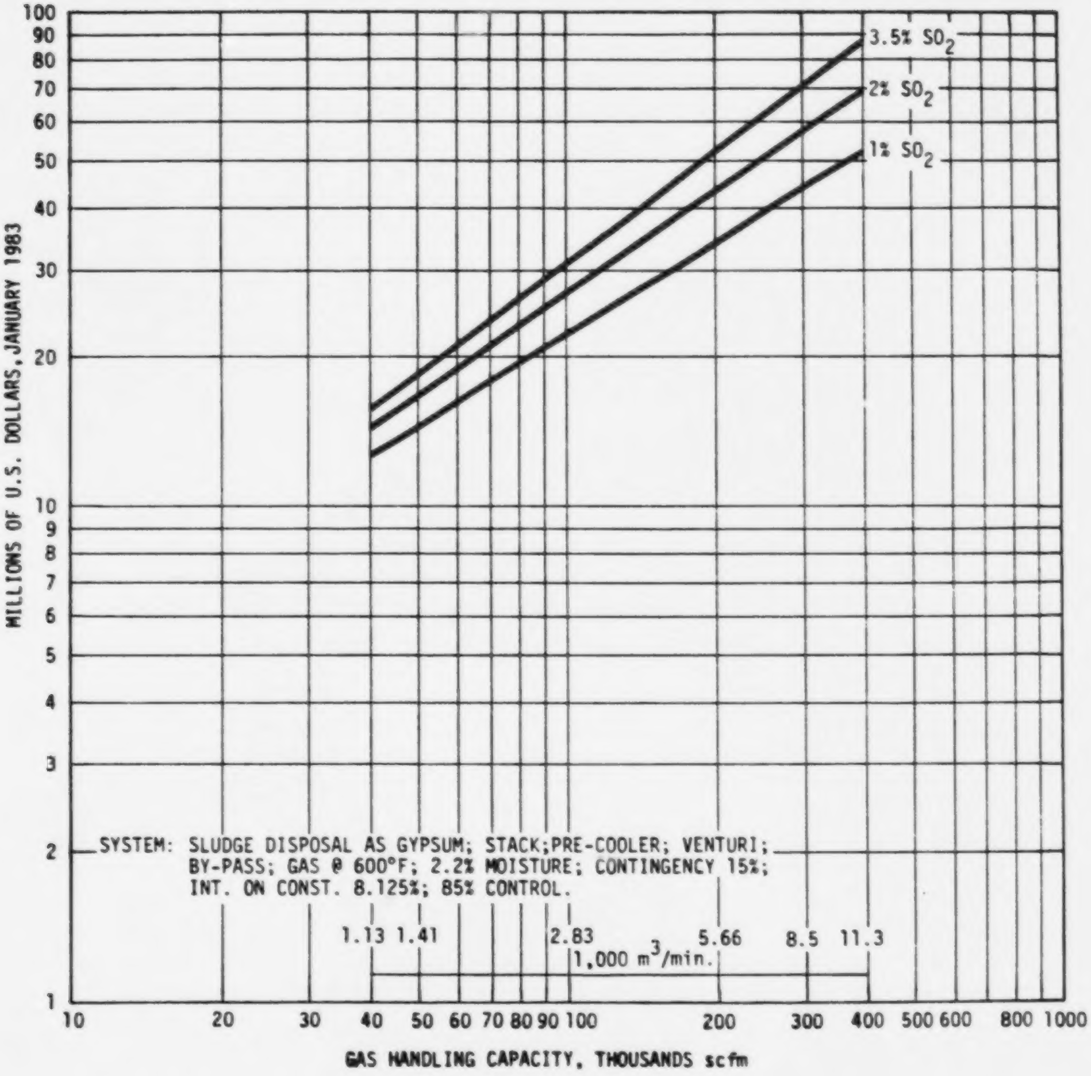


Figure 26. Capital cost of a limestone scrubbing FGS system.

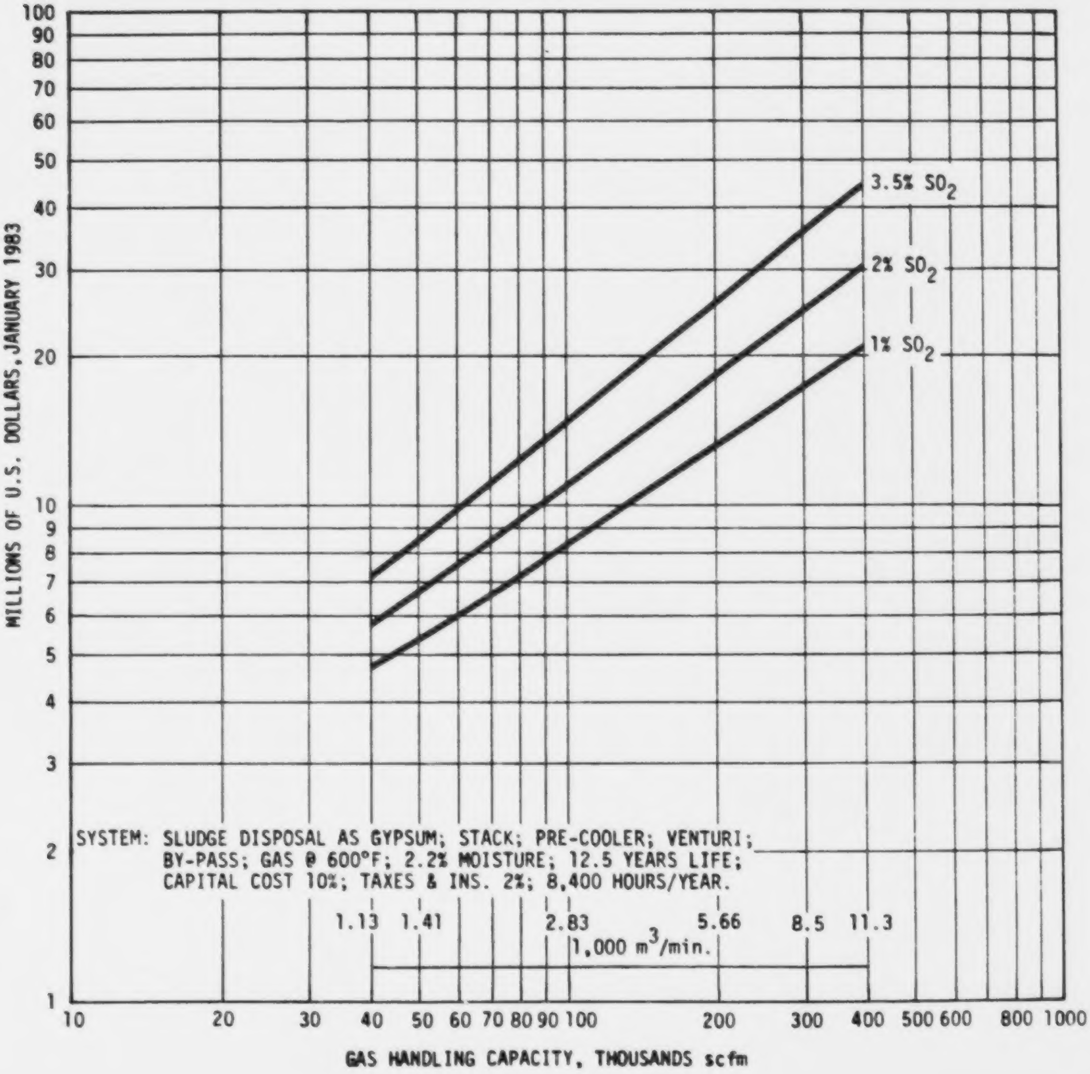


Figure 27. Annual operating costs of a limestone scrubbing FGS system.

A breakdown of the capital costs for a 1 and 3.5 percent SO_2 stream is presented in Table 31. As in the case of the lime-based system, the absorption system is the largest cost item.

Annual operating costs range from about $1767 to $6182 per m³/min ($50 to $175 per scfm). As shown in Table 32, which presents the annual operating costs for a 2,830 m³/min (100,000 scfm) system, the limestone reagent is the major direct operating cost, followed closely by maintenance charges. Fixed costs amount to more than 50 percent of the annual operating cost.

Although there is no direct relationship between off-gas flow and copper production for all smelters, the approximate cost for installing an FGS system on a reverberatory furnace with an equivalent annual production of 90,720 Mg (100,000 tons) is $22,000,000. The annual operating costs would be about $8,600,000 or $0.095/kg ($0.043/lb) of copper for the reverberatory furnace.

MAGNESIUM OXIDE SYSTEM

The magnesium oxide (MgO) process is a regenerable FGS system with an SO_2 removal efficiency of up to about 92 percent. Magnesium sulfite is formed in the absorption process and is then dried and calcined to regenerate and recover the MgO for reuse. The regeneration step produces a gas stream containing 10 to 13 percent SO_2, which can be converted to sulfuric acid, liquid SO_2, or elemental sulfur. The following basic reactions take place:

Magnesium oxide reagent slurry: $MgO + H_2O \rightarrow Mg(OH)_2$

Absorber: $SO_2 + Mg(OH)_2 + H_2O \rightarrow y\ MgSO_3 \cdot x\ H_2O + z\ MgSO_4$

Dryer/fluidized bed calciner: $y\ MgSO_3 \cdot x\ H_2O + z\ MgSO_4$

$\rightarrow MgO + w\ SO_2\uparrow + v\ H_2O\uparrow$

This scrubbing system uses a solution of magnesium oxide in water to absorb SO_2. Approximately 10 percent excess magnesium is used.

Process Description

The absorption portion of this process is very similar to the lime/limestone system (Figure 20). As the SO_2-laden gas stream ascends through the absorber diffuser trays, it is contacted countercurrently with the sprayed magnesium oxide absorbent at a rate of about 4.0 liters/m³ (30 gal/1000 acfm). The makeup MgO is prepared by mixing MgO with water to form a magnesium hydroxide solution (40 percent solids by weight) and then diluting it to a level of 10 percent solids.

TABLE 31. ESTIMATED CAPITAL COST OF A LIMESTONE-BASED FGS SYSTEM [2830 m³/min (100,000 scfm) of flue gas]

Item		Installed costs, $	
		For 1% SO_2	For 3.5% SO_2
1	Materials handling	1,614,400	5,086,900
2	Feed preparation	909,800	1,629,600
3	Pre-cooler	1,036,200	1,037,100
4	SO_2 scrubbing/venturi	5,156,800	5,156,200
5	Reheat and stack	2,429,600	2,429,600
6	Solids disposal	1,482,200	2,673,200
	Sub-total	12,629,000	18,012,600
7	Disposal pond	132,400	132,400
8	Cooling pond	638,900	646,800
	Total direct cost	13,400,300	18,791,800
		Indirect costs, $	
9	Indirects (31.25% of direct)	4,187,600	5,872,400
10	Interest during construction at 10% for 2.5 years	1,429,000	2,004,000
11	Contingency (15% of Items 1-6, 9, and 10)	2,852,500	4,000,200
	Indirects total	8,469,100	11,876,600
	Total capital costs	$21,869,400	$30,668,400
	Cooling pond liner cost	475,900	481,800

TABLE 32. ANNUAL OPERATING COSTS OF A LIMESTONE-BASED FGS SYSTEM

[2830 m³/min (100,000 scfm), 1% SO_2]

	Quantity	Unit cost	Annual cost, $
Raw materials			
Lime	9.83 Mg/h (10.84 tons/h) 8400 h/yr	$11.03/Mg ($10.00/ton)	910,900
Fixation chemicals	0.066 Mg/h (0.06 tons/h) 8400 h/yr	$55.13/Mg ($40.00/ton)	24,700
Utilities			
Water	666 liters/min (176 gpm) 8400 h/yr	$0.09/1000 liters ($0.35/1000 gal)	31,100
Electricity	1830 kW 8400 h/yr	$0.04 kWh	614,800
Operating labor			
Direct labor	5 men/shift	$9.60/man-hour	420,900
Supervision	15% of direct labor		63,100
Maintenance			
Labor and materials	4% of fixed cost		874,800
Supplies	15% of labor and materials		131,200
Overhead			
Plant	50% of operation and maintenance		745,000
Payroll	20% of operating labor		96,800
Fixed costs			
Depreciation	(8.0%)		
Taxes and insurance	(2.3%)		
Capital cost	(10.0%)		
	Sum = 20.3% of fixed investment		4,439,500
Trucking costs	$2.13/m³ ($2.785/yd³)		224,300
Total annual cost			8,577,100

As the gas stream leaves the absorber, it passes through a mist eliminator, is mixed with heated air to give a flue gas temperature of 80°C (175°F), and is then ducted to an induced-draft fan for discharge to the atmosphere through a new or existing stack.

The liquid bleed stream out of the absorber recirculation tank contains mostly magnesium sulfite, some magnesium sulfate, some unreacted slurry, and other trace impurities. The magnesium sulfite formed in this regenerable system is dried and calcined to form magnesium oxide and a high-strength SO_2 gas for further processing, as shown in Figure 28. About 92 percent of the absorbent from the absorber is recirculated. The remaining 8 percent is pumped to a liquid cyclone, the overflow is returned to the 10 percent dilution slurry tank, and the cyclone underflow is sent to a surge tank that feeds the multiple centrifuges. The centrifuges produce a wet cake, which is conveyed to a rotary dryer to remove the water. The liquor removed during centrifugation is returned to the 10 percent dilution makeup slurry tank. Dryer temperatures typically are in the range of 200° to 232°C (390° to 450°F). Products from the dryer are about 80 percent magnesium sulfite, and the remainder is basically hydroxide and magnesium sulfate.

The crystals out of the dryer are conveyed to a fluid-bed calciner, where they break down to form MgO and SO_2 at a temperature of 600° to 800°C (1100° to 1475°F). The recovered MgO is sent to a storage silo. This regenerated MgO (with 1 to 3 percent $MgSO_4$) is sent to a mix tank, where it is mixed with virgin MgO. A bleed stream for the removal of $MgSO_4$ from the 10 percent dilution tank is sent to a disposal pond or an emergency pond. The makeup solution from this dilution tank is pumped to the absorber recirculation tank.

The hot SO_2 gas released during calcining passes through a heat exchanger to preheat the combustion air for the calciner. This gas then goes to a cyclone, where MgO particles are collected and sent to the storage silo. The gas stream out of the cyclone, which contains approximately 10 percent SO_2, can be further processed in a liquid SO_2 plant, a sulfuric acid plant, or an elemental sulfur plant.

System Costs

The capital cost and annual operating costs for the MgO system without SO_2 recovery are shown in Figures 29 and 30 for gas streams containing 1 to 3.5 percent SO_2. These costs, which are based on 90 percent SO_2 removal, also include a pre-cooler and venturi scrubber to cool and clean the gas. No SO_2 recovery system such as a sulfuric acid or liquid SO_2 plant is included. These data show that capital costs range from about \$4415 to \$16,778 per m^3 (\$125 to \$475 per scfm). A breakdown of capital

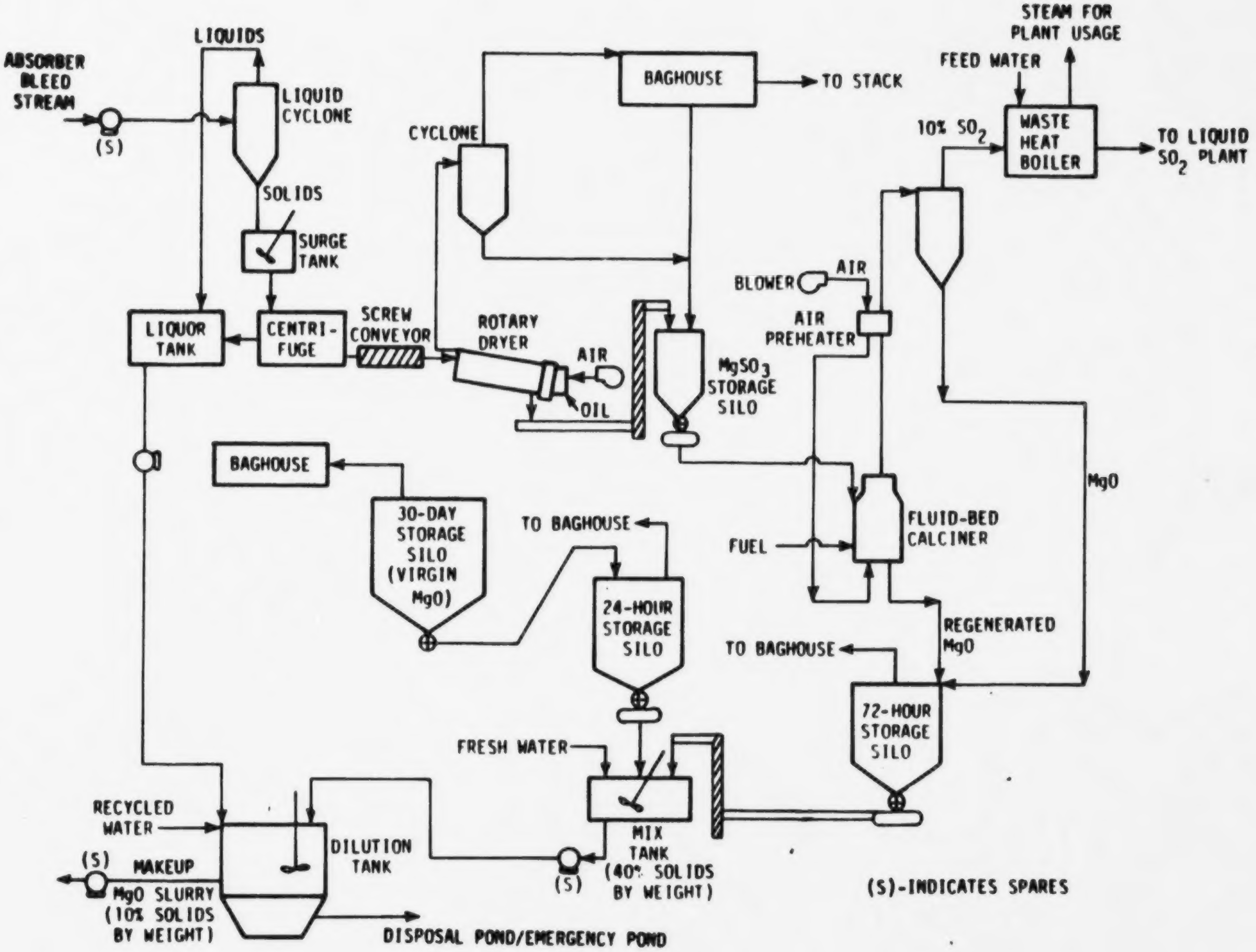

ABSORBER BLEED STREAM
(S)
LIQUIDS
LIQUID CYCLONE
SOLIDS
SURGE TANK
LIQUOR TANK
CENTRI-FUGE
SCREW CONVEYOR
ROTARY DRYER
AIR
OIL
CYCLONE
BAGHOUSE
TO STACK
MgSO3 STORAGE SILO
BLOWER
AIR
AIR PREHEATER
10% SO2
FEED WATER
STEAM FOR PLANT USAGE
WASTE HEAT BOILER
TO LIQUID SO2 PLANT
MgO
FUEL
FLUID-BED CALCINER
REGENERATED MgO
BAGHOUSE
30-DAY STORAGE SILO (VIRGIN MgO)
TO BAGHOUSE
24-HOUR STORAGE SILO
TO BAGHOUSE
72-HOUR STORAGE SILO
FRESH WATER
MIX TANK (40% SOLIDS BY WEIGHT)
(S)
RECYCLED WATER
(S)
MAKEUP
MgO SLURRY (10% SOLIDS BY WEIGHT)
DILUTION TANK
DISPOSAL POND/EMERGENCY POND
(S)-INDICATES SPARES

Figure 28. Schematic of the MgO makeup, storage, and recovery systems.

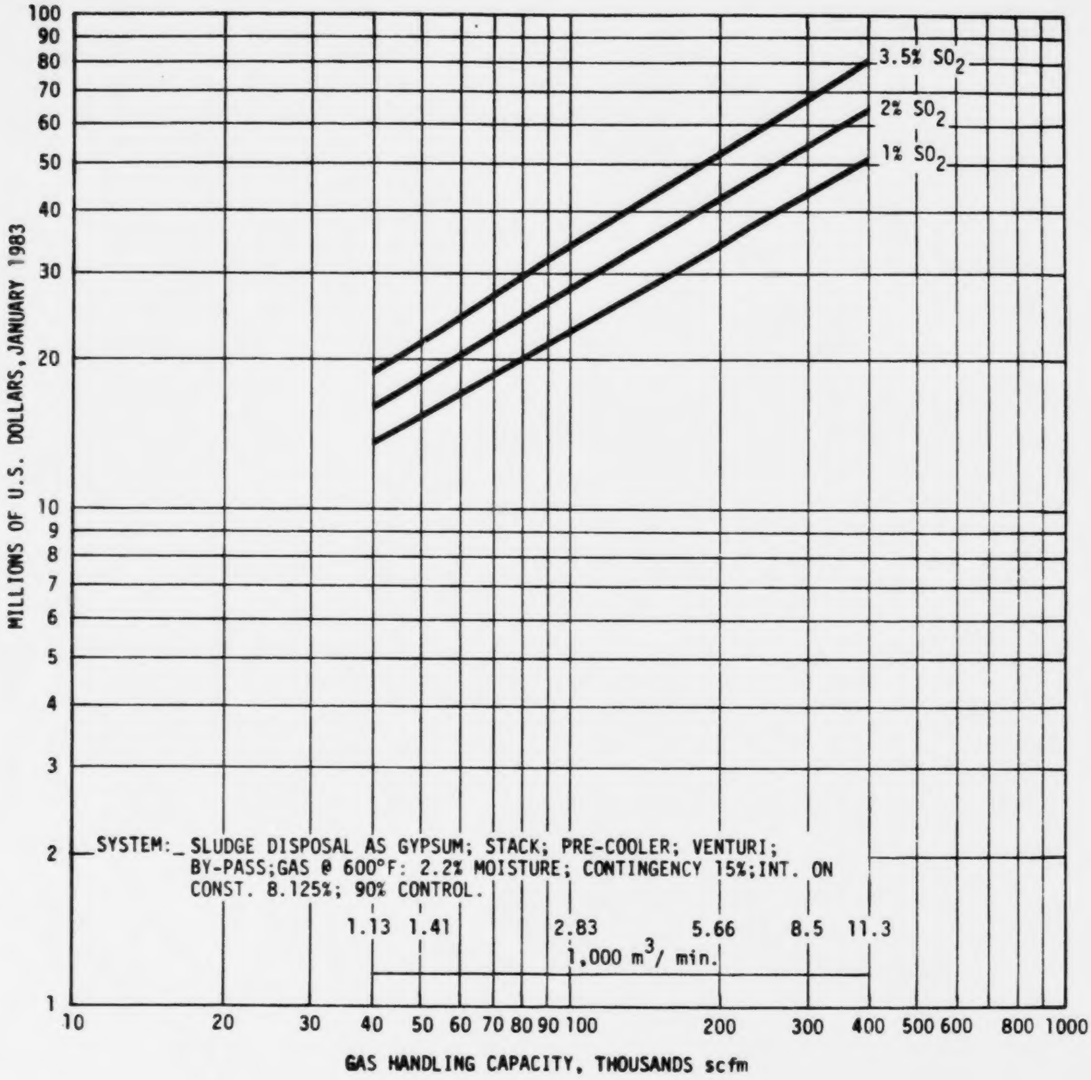


Figure 29. Capital cost of a magnesium oxide scrubbing FGS system (without SO_2 recovery equipment)

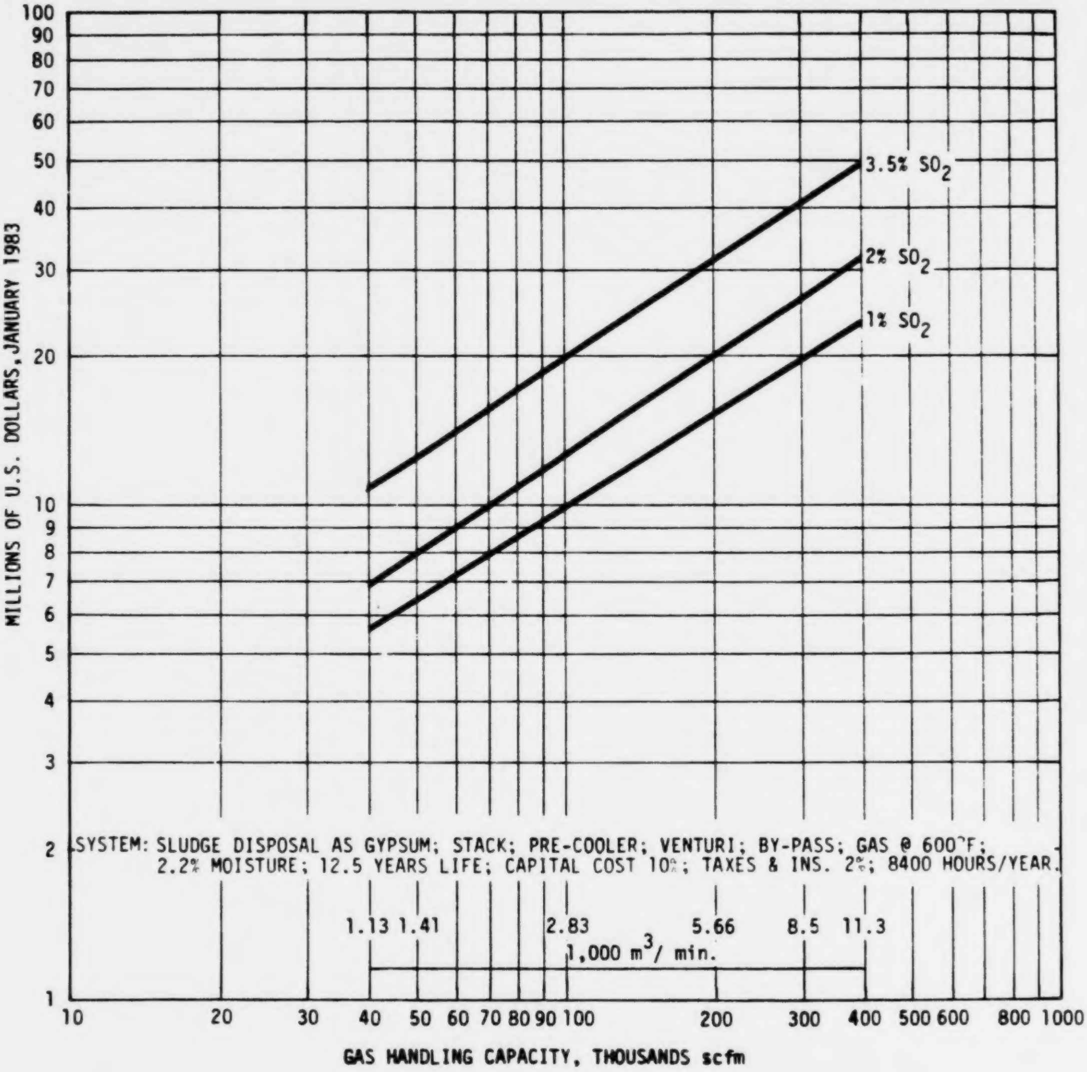


Figure 30. Annual operating costs of a magnesium oxide FGS system (without SO_2 recovery).

costs for controlling a 1 and 3 percent SO_2 stream is shown in Table 33. The absorption system and the MgO regeneration systems represent the major cost items.

Annual operating costs range from \$1589 to \$6182 per m³/min (\$45 to \$175 per scfm). As shown in Table 34, the fixed costs represent about one-half of these costs. Fuel for MgO regeneration is the major direct annual cost.

SODIUM CITRATE SYSTEM

Like the MgO system, the citrate FGS system is a regenerable type. Removal of SO_2 is enhanced by maintaining an optimum solution pH during the scrubbing process, which is accomplished by the use of sodium citrate, a good buffering agent. The absorption of SO_2 depends on the pH of the solutions; SO_2 removal is enhanced as the pH increases. No smelters use the citrate system on a full-scale basis, but Flakt (at the Boliden smelter in Sweden) and the Bureau of Mines (in the United States) have tested pilot-scale versions. Three citrate processes with efficiencies up to 95 percent are available: the Bureau of Mines Process, the Peabody Process, and the Flakt Process. The Flakt process is the one discussed here. The chemical reactions for the Flakt Process in the absorption stripping operation follow the simplified reactions given below.

$$SO_2(g) \rightarrow SO_2(aq)$$

$$SO_2(aq) + H_2O \rightarrow H^+ + HSO_3^-$$

$$H^+ + H_n\ Ci^{(3-n)} \rightarrow H_n + 1\ Ci^{(2-n)}$$

Process Description

As shown in Figure 20, the SO_2 stream passes up through a packed absorption tower after its pretreatment (if required), where it is met by a countercurrent aqueous stream of sodium citrate at a rate of 3.0 liters/m³ (22.4 gal/1000 acfm). The citrate solution (citric acid and sodium citrate) is a buffering agent that ties up hydrogen ions that form when SO_2 and water are brought together. The bonding of the hydrogen ions and the sodium radical that combines with the bisulfite ion maintains a relatively high pH and allows the dissolution of additional SO_2.

The scrubbed gas stream, from which 95 percent of the SO_2 has been removed from the top of the absorber, passes through a mist eliminator and is then mixed with heated air to increase its temperature by 28°C (50°F) before being ducted via an ID fan to a new or existing stack, in the same manner as the other scrubbing systems.

TABLE 33. ESTIMATED CAPITAL COST OF A MAGNESIUM-OXIDE-BASED FGS SYSTEM [2830 m³/min (100,000 scfm) of flue gas]

Item		Installed costs, $	
		For 1% SO_2	For 3.5% SO_2
1	Materials handling	385,000	831,300
2	Feed preparation	339,300	532,200
3	Pre-cooler	1,036,200	1,037,100
4	SO_2 scrubbing/venturi	4,702,800	4,702,200
5	Reheat and stack	2,429,600	2,429,600
6	Solids disposal	4,512,200	10,005,000
	Sub-total	13,405,100	19,537,400
7	Emergency pond	70,700	70,700
8	Cooling pond	638,900	646,800
	Total direct cost	14,114,700	20,254,900
		Indirect costs, $	
9	Indirects (31.25% of direct)	4,410,800	6,329,700
10	Interest during construction at 10% for 2.5 years	1,505,200	2,160,000
11	Contingency (15% of Items 1-6, 9, and 10)	3,004,600	4,311,700
	Indirects total	8,920,600	12,801,400
	Total capital costs	23,035,300	33,056,300
	Cooling pond liner cost	475,900	481,800

TABLE 34. ANNUAL OPERATING COSTS OF A MAGNESIUM OXIDE-BASED FGS SYSTEM
[2830 m³/min (100,000 scfm), 1% SO_2]

	Quantity		Unit cost	Annual cost, $
Raw materials				
Magnesium	0.15 Mg/h (0.17 tons/h)	8400 h/yr	$276/Mg ($250.00/ton)	358,400
Utilities				
Water	696 liters/min (184 gpm)	8400 h/yr	$0.09/1000 liters ($0.35/1000 gal)	32,400
Electricity	1329 kW	8400 h/yr	$0.04 kWh	446,500
Oil	1166 liters/h (308 gph)	8400 h/yr	$0.26 liters ($1.00/gal)	2,585,572
Operating labor				
Direct labor	6 men/shift		$9.60/man-hour	505,100
Supervision	15% of direct labor			75,800
Maintenance				
Labor and materials	4% of fixed cost			921,400
Supplies	15% of labor and materials			138,200
Overhead				
Plant	50% of operation and maintenance			820,200
Payroll	20% of operating labor			116,200
Fixed costs				
Depreciation	(8.0%)			
Taxes and insurance	(2.3%)			
Capital cost	(10.0%) Sum = 20.3% of fixed investment			4,676,200
			Total annual cost	10,675,972

The SO_2-rich (in the form of sodium bisulfite) citrate solution leaving the absorber is pumped through a preheater to the top of the stripper (see Figure 31). Low-pressure steam* is used in the stripper to remove the SO_2 from the solution. Thus, the sodium citrate solution is regenerated, pumped back to the system, and used again as the scrubbing medium. The SO_2 gas and some water leave the top of the stripper and pass through a cold-water condenser. The gas stream passes first through the mist eliminator at the top of the stripper for removal of entrained droplets and then through a noncontact water condenser for cooling and condensing most of the water vapor from the gas stream. The condensed water, which contains a small amount of SO_2, is returned to the stripper. The stream that leaves the condenser is water vapor (~2.3% by weight) and sulfur dioxide gas (97.7% by weight). This stream can then be processed to recover the sulfur value.

Approximately 2 percent of the regenerated sodium citrate solution is purged from the system to prevent the buildup of sodium sulfate.

System Costs

Figures 32 and 33 present estimated capital and annual operating costs of the citrate system for gas streams containing 1 to 3.5 percent SO_2. The capital cost includes a venturi scrubber to clean and cool the gas stream, but it does not include any recovery system for the resulting concentrated SO_2 stream. A refigeration system to condense the resulting concentrated SO_2 stream would add about 15 to 20 percent to the capital costs. These costs range from \$3,709 to \$14,130 per m^3 (\$105 to \$400 per scfm). Table 35 presents a breakdown of the capital cost. These data show that the gas contactor/venturi system is the most costly direct equipment item.

Annual operating costs range from \$1325 to \$4062 per m^3/min (\$37.50 to \$115 per scfm) without credit for recovered sulfur values. As shown in Table 36, which presents a breakdown of the annual operating costs, the major operating costs are for electricity and maintenance. With good recovery, citric acid makeup costs are minimized. Credit for recovered SO_2 would greatly reduce the annual costs.

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* Hot water and vacuum could also be used.

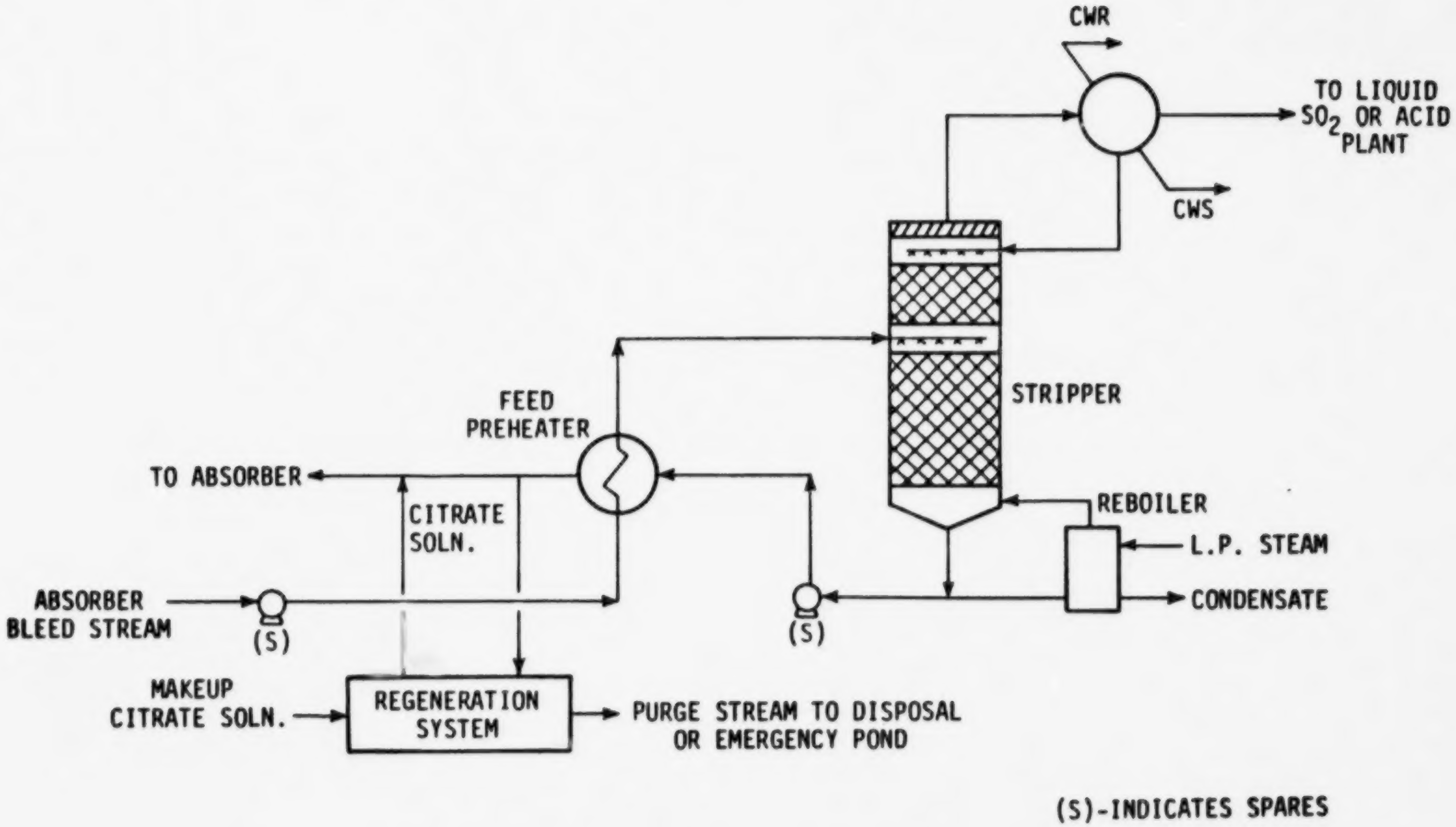

CWR
TO LIQUID
SO_2 OR ACID
PLANT
CWS
STRIPPER
FEED
PREHEATER
TO ABSORBER
CITRATE
SOLN.
REBOILER
L.P. STEAM
CONDENSATE
ABSORBER
BLEED STREAM
(S)
(S)
MAKEUP
CITRATE SOLN.
REGENERATION
SYSTEM
PURGE STREAM TO DISPOSAL
OR EMERGENCY POND
(S)-INDICATES SPARES

Figure 31. Schematic of the citrate removal and regeneration systems.

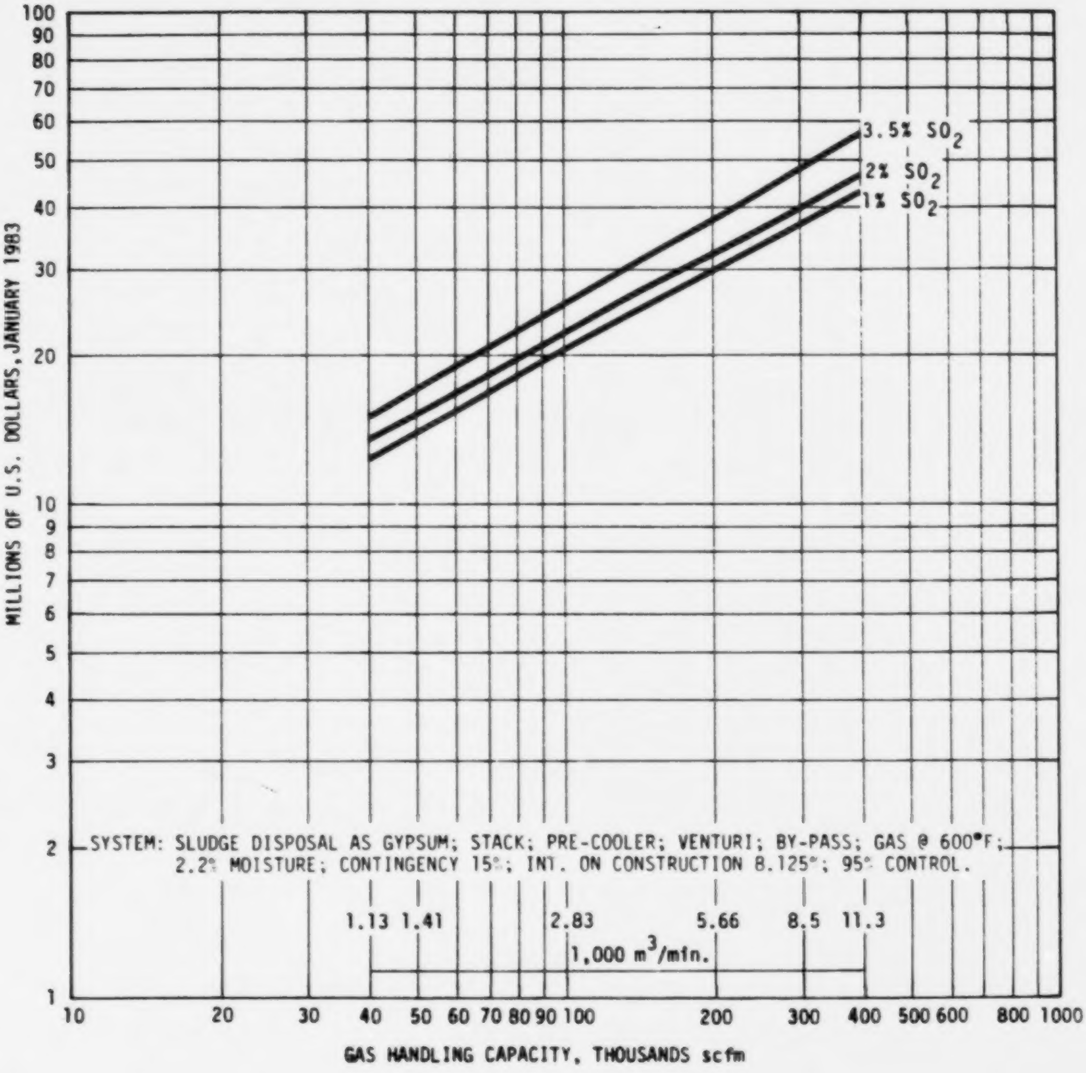
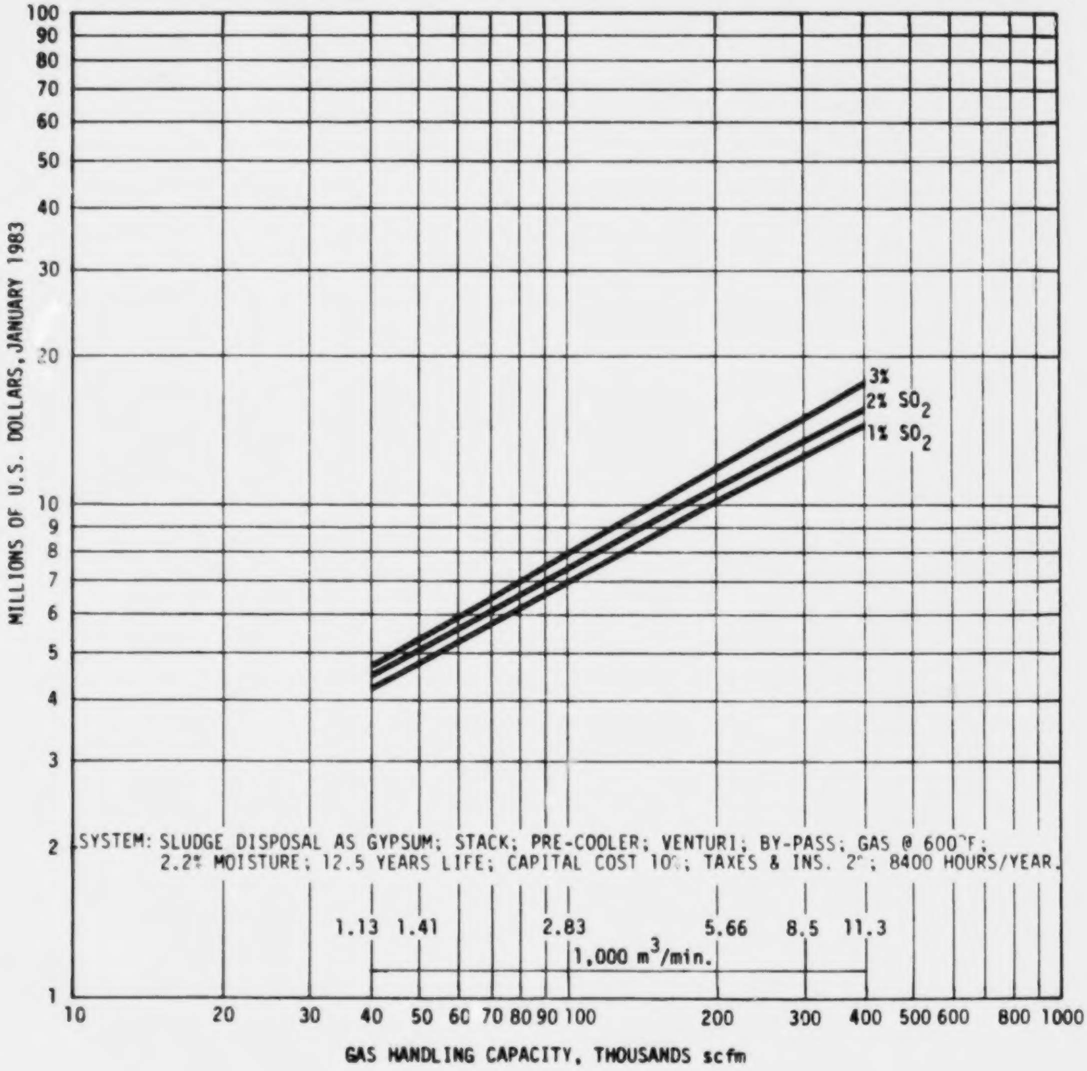


Figure 32. Capital cost of a Flakt citrate scrubbing FGD system (without a liquid SO_2 plant).



SYSTEM: SLUDGE DISPOSAL AS GYPSUM; STACK; PRE-COOLER; VENTURI; BY-PASS; GAS @ 600°F; 2.2% MOISTURE; 12.5 YEARS LIFE; CAPITAL COST 10%; TAXES & INS. 2%; 8400 HOURS/YEAR.

Figure 33. Annual operating costs of a Flakt citrate scrubbing FGD system (without a liquid SO_2 plant).

TABLE 35. ESTIMATED CAPITAL COST OF A CITRATE-BASED FGS SYSTEM
[2830 m³/min (100,000 scfm) of flue gas]

Item		Installed costs, $	
		For 1% SO_2	For 3.5% SO_2
1	Pre-cooler	1,036,200	1,037,100
2	SO_2 scrubbing/venturi	5,248,700	5,248,200
3	Reheat and stack	2,429,600	2,429,600
4	Citrate regeneration	2,190,400	3,719,100
5	Purge stream regeneration	526,500	816,300
	Sub-total	11,431,400	13,250,300
6	Emergency pond	54,800	54,800
7	Cooling pond	1,345,700	1,353,500
	Total direct cost	12,831,900	14,658,600
		Indirect costs, $	
8	Indirects (31.25% of direct)	4,010,000	4,580,800
9	Interest during construction at 10% for 2.5 years	1,368,400	1,563,200
10	Contingency (15% of Items 1-5, 8, and 9)	2,731,500	3,120,400
	Indirects total	8,109,900	9,264,400
	Total capital costs	20,941,800	23,923,000
	Cooling pond liner cost	1,000,900	1,006,800

TABLE 36. ANNUAL OPERATING COSTS OF A CITRATE-BASED FGS SYSTEM
[2830 m^3/min (100,000 scfm), 1% SO_2]

	Quantity		Unit cost	Annual cost, $
Raw materials				
Citric acid	0.0017 Mg/h (0.0019 ton/h)	8400 h/yr	$1091/Mg ($990/ton)	16,100
Soda ash	0.0127 Mg/h (0.0155 tons/h)	8400 h/yr	$116/Mg ($105/ton)	13,700
Utilities				
Water	1469 liters/min (388 gpm)	8400 h/yr	$0.09/1000 liters ($0.35/1000 gal)	
Electricity	1502 kW	8400 h/yr	$0.04/kWh	504,700
Operating labor				
Direct labor	4 men/shift		$9.60/manhour	336,700
Supervision	15% of direct labor			50,500
Maintenance				
Labor and materials	4% of fixed cost			837,700
Supplies	15% of labor and materials			125,700
Overhead				
Plant	50% of operation and maintenance			675,300
Payroll	20% of operating labor			77,400
Fixed costs				
Depreciation	(8.0%)			
Taxes and insurance	(2.3%)			
Capital cost	(10.0%)			
	Sum = 20.3% of fixed investment			4,251,200
		Total annual cost		6,957,500

SECTION 4

CONTROL OF STRONG SULFUR DIOXIDE STREAMS

Control of strong sulfur dioxide streams (i.e., those streams with more than about 4 percent SO_2) at nonferrous smelters is largely accomplished by the use of sulfuric acid plants and, to a lesser extent, sulfur or liquid SO_2 recovery facilities. Some of the regenerative scrubbing systems, such as the magnesium oxide or citrate processes, also include a sulfur recovery system. This section presents brief process descriptions and cost data for sulfuric acid plants and liquid SO_2 recovery systems.

SULFURIC ACID PLANTS

Sulfuric acid plants are used at nonferrous primary smelters to reduce emissions of SO_2 and to produce sulfuric acid. These plants differ from conventional sulfur-burning plants in that they must handle gas streams containing relatively low and variable amounts of SO_2.[43] The costs incurred in the installation of a sulfuric acid plant form a significant part of a smelter's overall SO_2 emission control program.

The cost of installing and operating an acid plant facility depends primarily on the following factors:

- Strength of SO_2 in the gas stream
- Gas flow rate
- Variations in SO_2 concentration in the gas stream
- Plant configuration and available space
- Disposal of sulfuric acid product, location of available market, and demand

The basic sulfuric acid plant is designed for efficient utilization of the heat generated by the exothermic formation of sulfur trioxide (SO_3) from SO_2.

A minimum SO_2 concentration of 3.5 to 4 percent is required to keep a single-contact/single-absorption sulfuric acid plant autothermal with a SO_2 removal efficiency of 97 to 98 percent. For a double-contact/double-absorption plant, autothermal operation can be maintained at a minimum concentration of 4 percent with a 99+ percent SO_2 removal efficiency.

Emissions of SO_2 from new acid plants are limited to 2 kg/Mg (4 lb/ton) of acid by Federal New Source Performance Standards. This relatively low limit generally requires the installation of a double-contact plant with an efficiency of at least 99.7 percent.

Table 37 presents a comparison of the key differences between single- and double-contact acid plants.

TABLE 37. COMPARISON OF SINGLE- AND DOUBLE-CONTACT ACID PLANTS

	New plant capital cost[a]	Power required	Tailgas, ppm SO_2	Production
Single-contact	0.88x	0.714y	1500	0.983z
Double-contact	x	y	500	z

[a] Basic plant excluding storage, rail, and trucking facilities.

Conversion of an existing single-contact plant to a double-contact would require the following items:

- ° New final absorption tower, with the existing tower becoming the intermediate absorption tower
- ° Additional heat exchangers, ducting, and piping
- ° Additional pumps
- ° Increased blower capacity
- ° Additional tanks
- ° Additional bed(s) in the converter or a supplemental converter and vanadium pentoxide catalyst
- ° Foundations, piping, structural steel, instrumentation, electrical work, insulation, etc.

The costs presented are based on a double-contact/double-absorption (DC/DA) acid plant with an SO_2 conversion efficiency of 99.5 percent. The plant receives gases from the smelter after particulates have been removed by electrostatic precipitators or some equivalent equipment. The plant can utilize gases with SO_2 concentrations ranging from 4 to 12 percent. As shown in Figure 34, the acid plant includes a gas-cleaning section and a conversion/absorption section. The cleaning section consists of a gas-washing or humidifying tower and a weak-acid stripper, followed by a packed tower and mist precipitators. The conversion section consists of a gas-drying tower with an acid stripper, heat exchangers, and a catalyst-bed converter (four- or five-stage). The absorption section consists of intermediate and final gas absorption towers and an acid storage area. In a single-contact acid plant, only one absorber is used, no intermediate heat exchanger is required, and the heat exchanger train is more simplified. A gas preheat furnace is included for use during startups and when the SO_2 strength in the gas stream from the smelter drops below about 4 percent for prolonged periods.

Figure 35 presents the capital and annual operating costs for double-contact acid plants. The "turnkey capital costs" of a plant with a capacity of 907 Mg (1000 tons) per day indicate nearly a 55 percent capital cost differential between an acid plant receiving a 4 percent SO_2 gas stream and one receiving an 8 percent SO_2 gas stream ($31 vs. $48 million). Figure 36 shows annual operating cost per Mg (ton) of sulfuric acid, based on 340 days of operation with no credit for acid product. No fuel oil costs are shown for startup or fluctuation in the percent of SO_2 in the gas stream to the smelter. The annual operating cost differential between a 4 percent and an 8 percent SO_2 concentration is 48 percent [$21.80/Mg ($19.77/ton) at 4 percent vs. $14.73/Mg ($13.36/ton) at 8 percent for a 907 Mg (1000 tons) per day plant]. Power consumption is 56 percent more for a 4 percent SO_2 stream than for an 8 percent SO_2 stream.

The costs shown are the capital (turnkey) costs (excluding land costs and permitting) and annual direct operating costs of a double-contact sulfuric acid plant applied to nonferrous smelter off-gases. Acid storage facility costs are also shown, based on storage for 5 days of full operation handling either rail and truck shipments or both of sulfuric acid from the smelter. The costs were based on in-house data and vendor information. These costs were compared with other published technical studies, and they were adjusted to January 1983 dollars by appropriate Chemical Engineering Cost Index factors.

Figure 37 presents the capital and annual costs for acid storage facilities, based on a 5-day storage capacity and transportation by rail or truck.

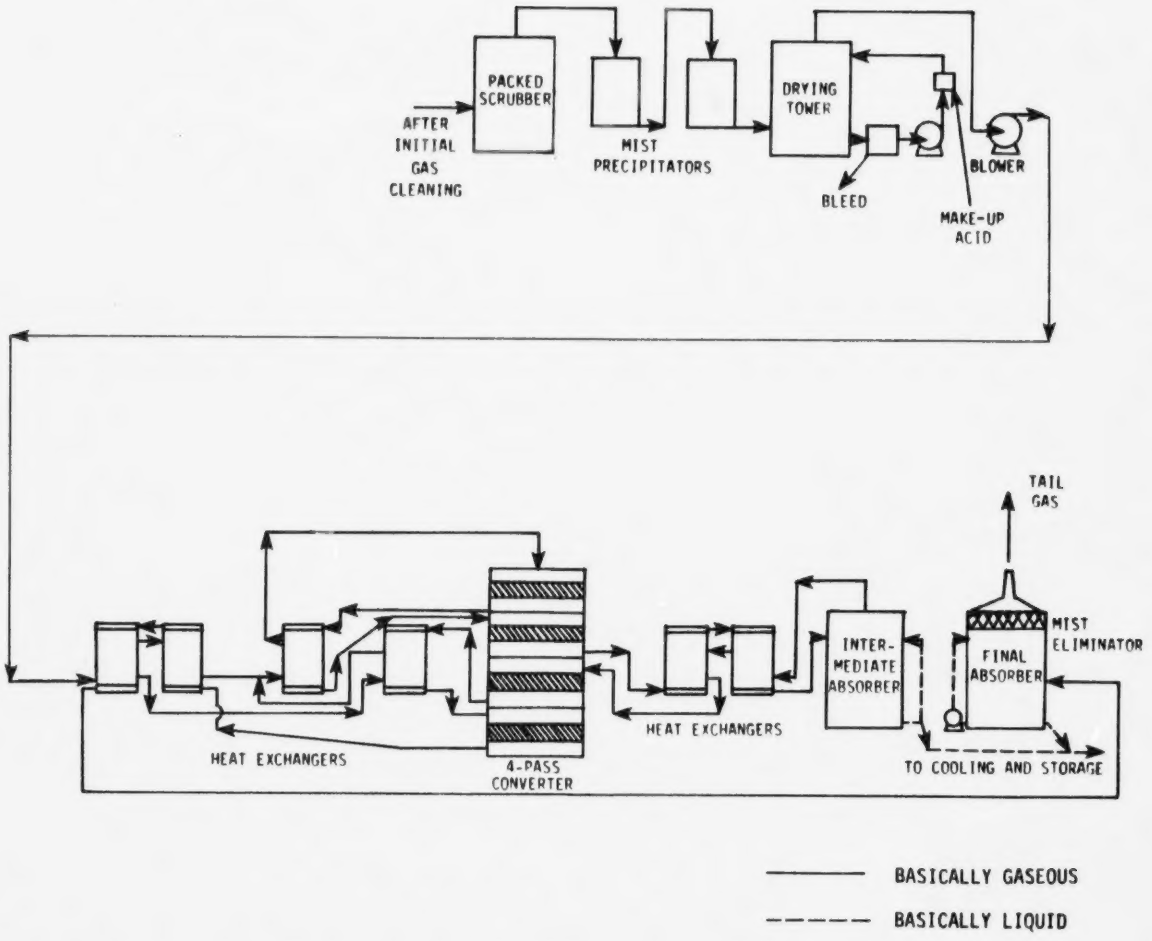

AFTER INITIAL GAS CLEANING
PACKED SCRUBBER
MIST PRECIPITATORS
DRYING TOWER
BLEED
MAKE-UP ACID
BLOWER
HEAT EXCHANGERS
4-PASS CONVERTER
HEAT EXCHANGERS
INTER-MEDIATE ABSORBER
TAIL GAS
MIST ELIMINATOR
FINAL ABSORBER
TO COOLING AND STORAGE
BASICALLY GASEOUS
BASICALLY LIQUID

Figure 34. Double-absorption/double-contact acid plant.

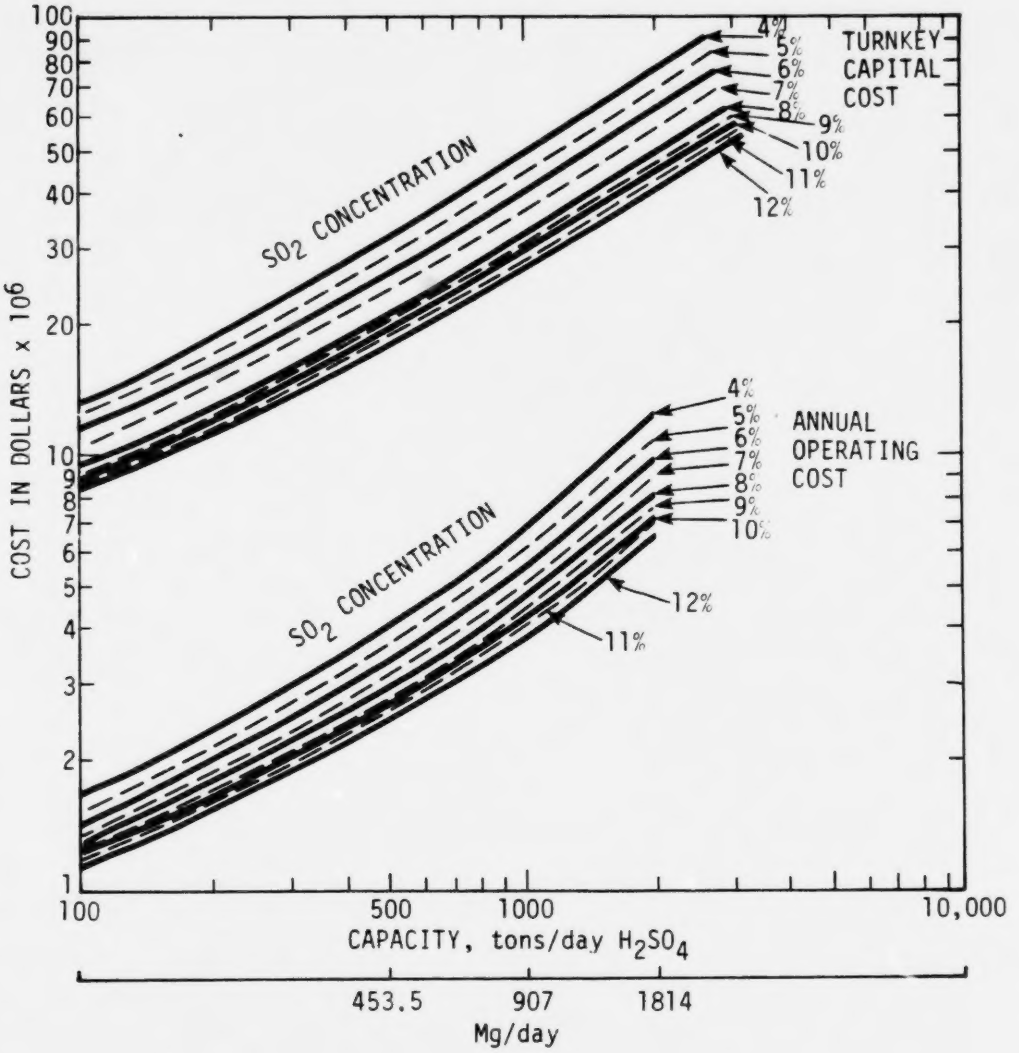


Figure 35. Capital and annual operating costs in January 1983 dollars. (Capital costs do not include cost of capital, land costs, preliminary costs for permits, or environmental reviews. Annual costs do not include taxes, insurance, depreciation, interest on capital, or credit for product acid.)

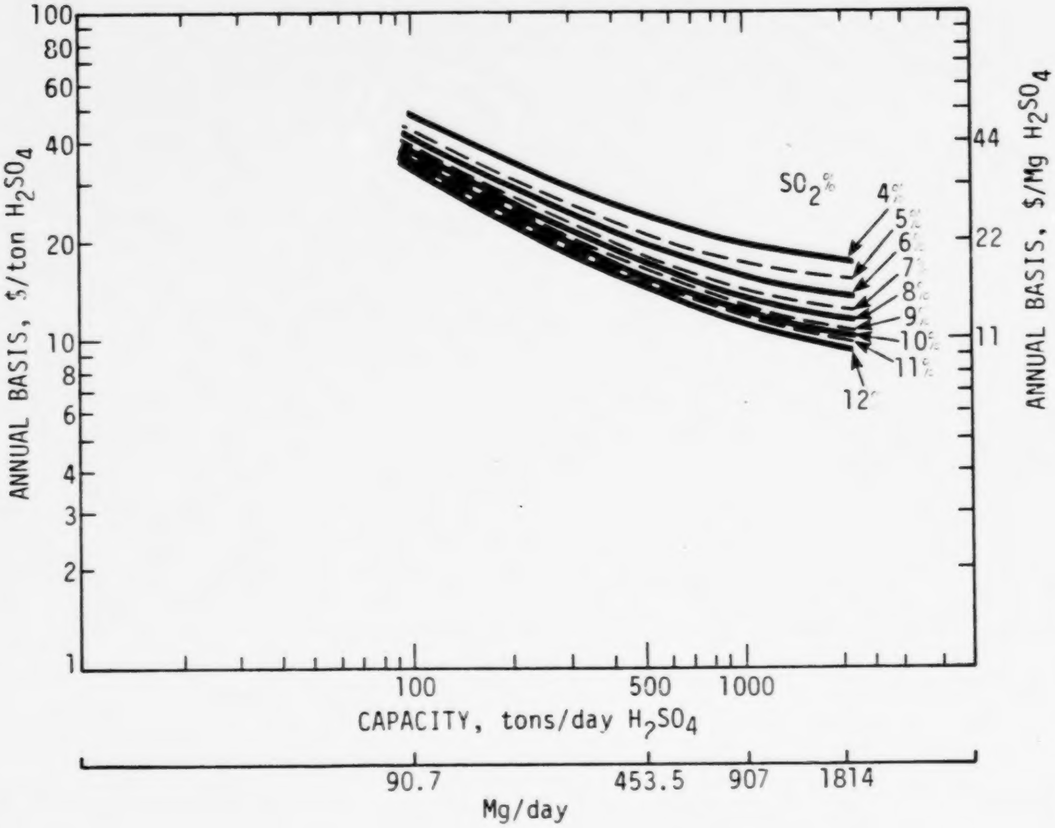


Figure 36. Direct annual operating cost per ton of sulfuric acid in January 1983 dollars (based on 340 days of operation per year and no acid credit).

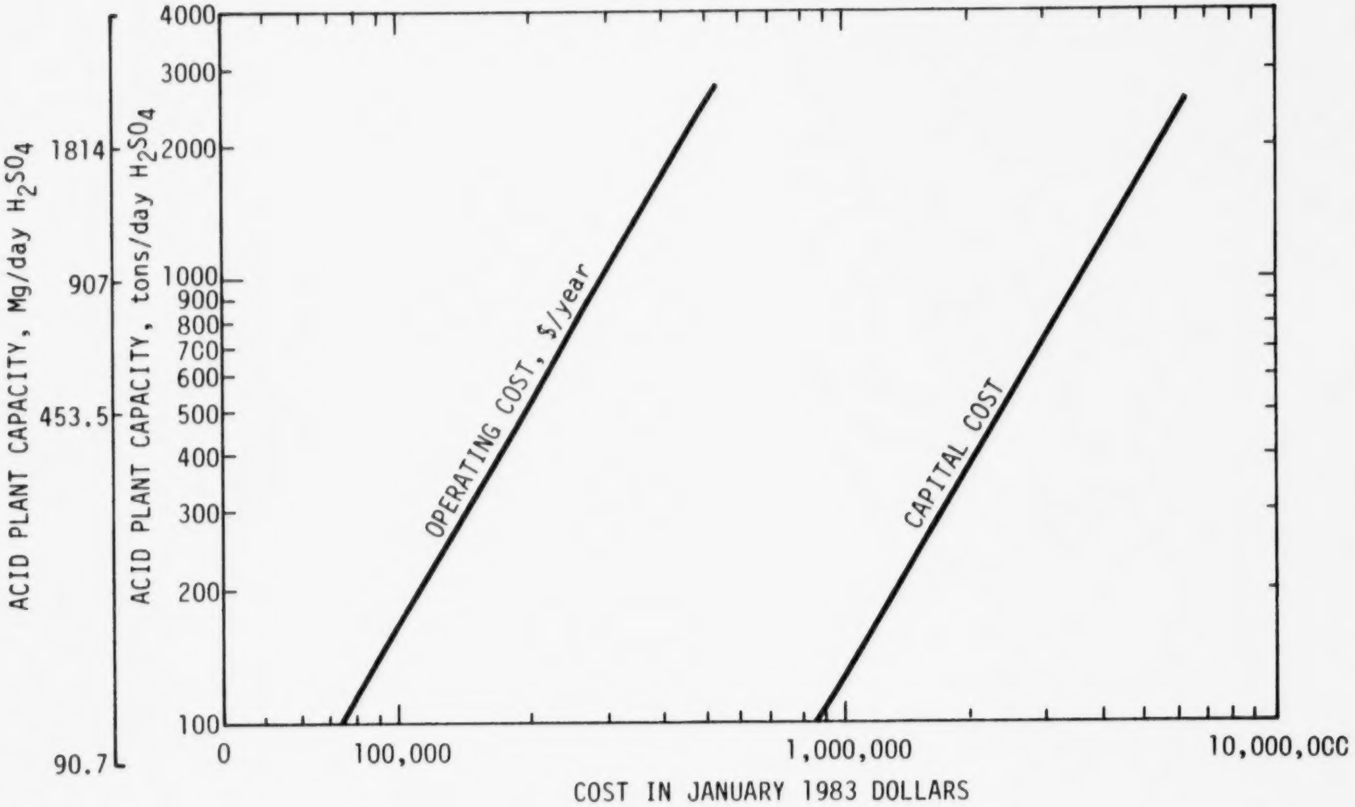


Figure 37. Capital and annual operating costs of 5-day acid storage facility.

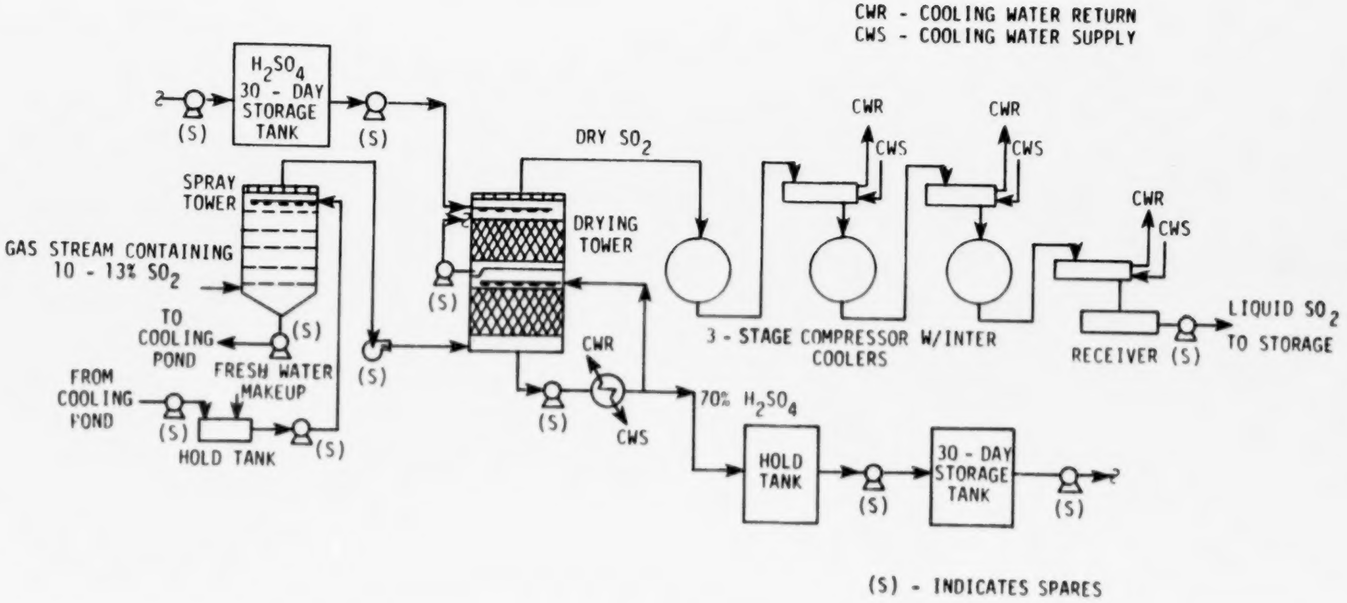
The economics of the sulfuric acid plant become more favorable as capacity increases and the strength of the SO_2 in the stream becomes higher.

LIQUID SO_2 PROCESSES

Because liquid SO_2 commands a much higher price than sulfuric acid, production of this compound may be advantageous if a market is available. Two types of liquid SO_2 systems are described. Figure 38 presents a schematic of a liquid SO_2 system that uses compression. This type of system can be used with gas streams containing at least 10 percent SO_2. For example, the SO_2 in the gas stream leaving the calciner in the magnesium oxide FGS system could be recovered in liquid form with this system. In the magnesium oxide process, the gas stream from the waste-heat boiler, which contains 10 to 13 percent SO_2, is further cooled in a spray tower. The cooled stream is sent to a drying tower, where concentrated H_2SO_4 (98 percent) is used to remove the remaining moisture from the gas stream. Part of the diluted acid stream is recirculated through a drying tower, and the rest is returned to the acid plant, where it is reconcentrated. The resulting gaseous stream from the drying tower is then compressed by a multistage compressor system and the SO_2 is condensed in liquid form. The liquid SO_2 is pumped to a receiver, and the noncondensible gases (largely nitrogen, oxygen, and carbon dioxide) are vented off.

For high concentrations of SO_2 (~90 percent or greater), a refrigeration-type SO_2 liquefication system is used. Such a gas stream could result from the citrate FGS system (Section 3) or directly from a flash smelter. In this system, the gas must be cleaned and then dried by scrubbing with sulfuric acid. The dry gas stream from the drying tower (which is nearly 100 percent SO_2) is sent to a refrigeration system, where the SO_2 is cooled, liquefied, and pumped to a receiver, as shown in Figure 39.

The total capital and related costs for the application of a liquid SO_2 recovery system to a magnesium oxide or citrate scrubbing system are shown in Figure 40. The refrigeration system on the citrate scrubbing system handles a fairly pure SO_2 stream, whereas the compression system on the magnesium oxide system handles a much more dilute SO_2 stream. In the size range needed for smelter off-gases, however, the two systems are similar in cost. The installed cost of a compression-type liquid SO_2 system is in the \$3,000,000 to \$12,000,000 range and accounts for about 15 percent of the entire cost of the scrubbing SO_2-recovery system. The refrigeration-type system on a citrate scrubbing system accounts for about 20 percent of the cost of the scrubbing SO_2-recovery system.



CWR - COOLING WATER RETURN
CWS - COOLING WATER SUPPLY
H_2SO_4 30 - DAY STORAGE TANK
(S)
(S)
SPRAY TOWER
GAS STREAM CONTAINING 10 - 13% SO_2
TO COOLING POND
(S)
FROM COOLING POND
(S)
FRESH WATER MAKEUP
HOLD TANK
(S)
(S)
DRYING TOWER
(S)
DRY SO_2
(S)
CWR
CWS
70% H_2SO_4
HOLD TANK
(S)
30 - DAY STORAGE TANK
(S)
CWR
CWS
CWR
CWS
3 - STAGE COMPRESSOR W/INTER COOLERS
CWR
CWS
RECEIVER (S)
LIQUID SO_2 TO STORAGE
(S) - INDICATES SPARES

Figure 38. Schematic of the compression-type liquid SO_2 system.

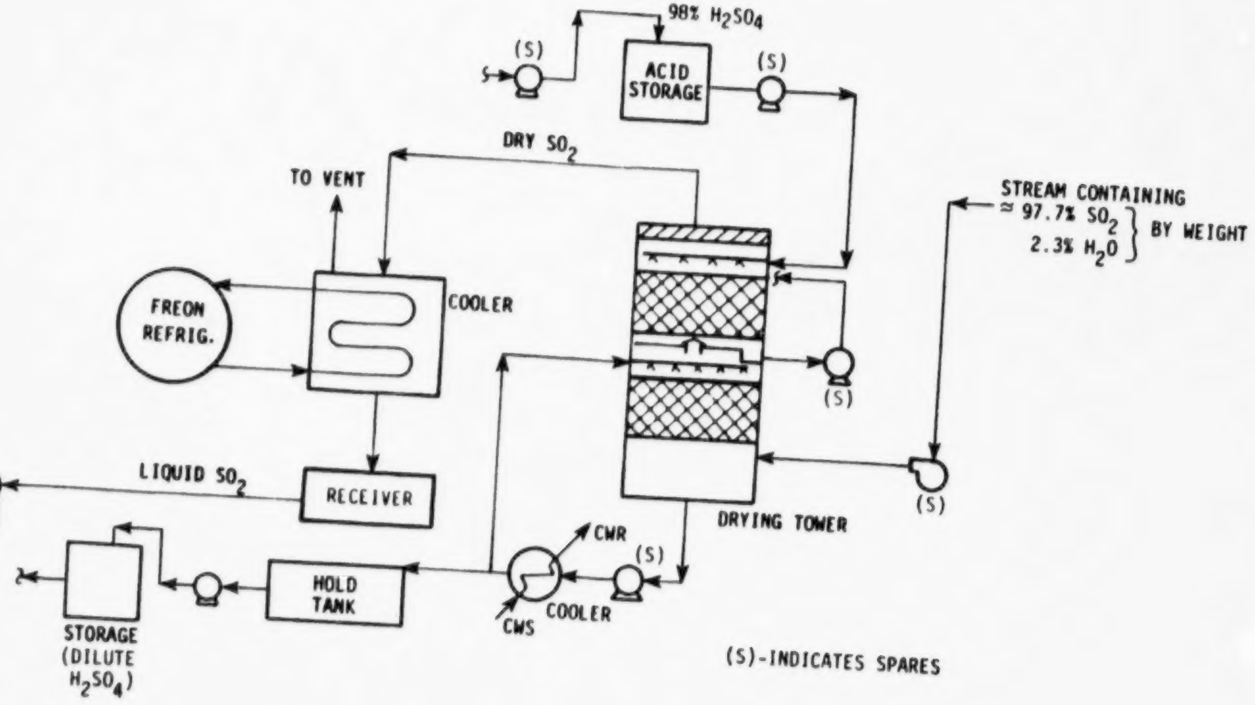

98% H_2SO_4
(S)
ACID STORAGE
(S)
DRY SO_2
TO VENT
STREAM CONTAINING
≈ 97.7% SO_2
2.3% H_2O
BY WEIGHT
FREON REFRIG.
COOLER
(S)
TO STORAGE
LIQUID SO_2
RECEIVER
(S)
DRYING TOWER
(S)
CWR
(S)
HOLD TANK
CWS
COOLER
STORAGE (DILUTE H_2SO_4)
(S)-INDICATES SPARES

Figure 39. Schematic of a refrigeration-type liquid SO_2 system.

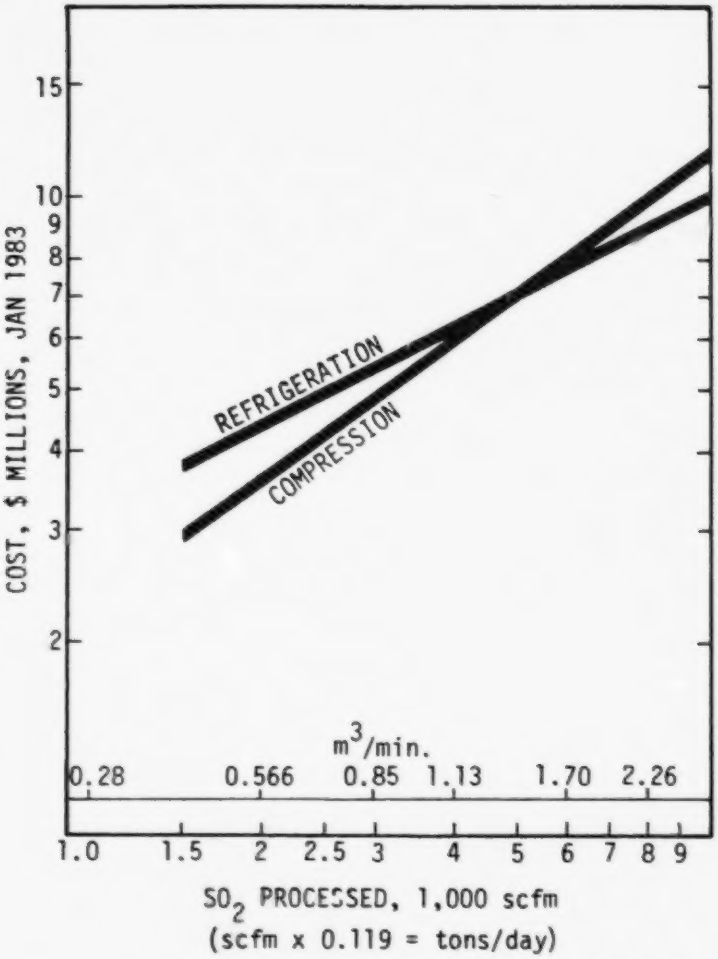


Figure 40. Cost of liquid SO_2 production systems. Flows are at 70°F and 29.92 in. Hg.

SECTION 5

SO_2 CONTROL SYSTEM COST COMPARISONS

This section presents costs for the process modifications and SO_2 controls discussed in Sections 2, 3, and 4. For comparison purposes, the costs are all based on a domestic model smelter (as opposed to Greenfield) producing 90,720 Mg (100,000 tons) per year of blister copper. Because detailed design and site-specific information are not available, the costs are approximate, and they should be used primarily for comparison purposes. Off-gas flow rates and the SO_2 concentrations represent average values, including some air in-leakage. These rates could vary widely from plant to plant, depending on the condition of the furnace(s), the ductwork, and the operating practices. Other factors that affect the costs include ore composition (Cu, Fe, S), "dirty" ore (high in arsenic, lead, etc.), turndown ratio, salability and disposal of captured SO_2 as H_2SO_4 (or liquid SO_2 or neutralization), and the cost of utilities.

COST SUMMARY

A cost comparison of various process modifications that yield off-gases that can be processed in a sulfuric acid plant is presented in Table 38.

The total capital and annual operating costs for the process modifications, including a double-contact acid plant, are shown for each smelting process. The capital costs represent the equipment and labor required to modify an existing plant to the specified process. The annual operating costs only represent the smelting cost with the designated process, not the entire copper production cost. The acid plant costs are also shown separately because they represent a major portion of the total cost. The acid plant capacity is 1175 Mg/day (1075 tons/day), which includes a 20 to 25 percent allowance over the average required size. The acid plant cost varies because of the different SO_2 concentrations. These data show that capital costs (including a new double-contact acid plant) range from \$741 to \$964/Mg (\$672 to \$875/ton) of annual capacity. Annual operating costs [including indirect charges and a credit of \$22/Mg (\$20/ton) for sulfuric acid and steam credit] range from \$0.275 to \$0.358/kg (\$0.125

TABLE 38. PROCESS MODIFICATION AND ACID PLANT COSTS[a]

Process[b]	Average flow,[c] m³/s (scfm)	% SO_2 by volume[d]	Capital cost, $ x 10^6	Annualized cost, $ x 10^6	Capital cost per Mg (ton) of annual capacity, $	Annualized smelting cost per kg (lb) of copper, $
INCO acid plant only	27.4 (58,100)	8.5	67.2 39.7	25.0 7.2	741 (672) 438 (397)	0.275 (0.125) 0.079 (0.036)
Oxygen sprinkle acid plant only	31.9 (67,700)	7.3	74.4 45.1	27.9 8.7	820 (744) 497 (451)	0.307 (0.139) 0.096 (0.044)
Oxy-fuel acid plant only	35.3 (96,000)	5.0	81.7 53.7	32.5 11.7	901 (817) 592 (537)	0.358 (0.163) 0.129 (0.059)
Noranda	29.5 (62,600)	7.9	76.5 40.2	25.1 7.5	843 (765) 443 (402)	0.277 (0.126) 0.083 (0.038)
Outokumpu Oy	34.8 (73,800)	6.7	87.5 47.6	32.1 9.7	964 (875) 525 (476)	0.355 (0.161) 0.108 (0.049)
Mitsubishi	19.4 (41,200)	12.0	78.0 36.5	30.1 5.5	860 (780) 402 (365)	0.333 (0.151) 0.062 (0.028)

[a] Based on installing or modifying equipment at an existing smelter with annual production of 90,720 Mg (100,000 tons) of blister copper. Sulfur in concentrate amounts to 102,084 Mg (112,500 tons)/yr and 95% is controlled. The remaining ±5% is lost in slag, fugitive emissions, and acid plant blowdown.

[b] Acid plant cost is included in total cost and shown separately to show its portion of the total cost; also includes taxes, insurance, depreciation, and interest on capital. Credit for sulfuric acid at $22/Mg ($20/ton) and steam as generated electricity is included as applicable.

[c] Total off-gas flow, including that from the converter.

[d] Average SO_2 concentrations from smelter and converter.

to $0.161/ton) of blister copper. The acid plant accounts for more than 50 percent of the capital cost, except in the case of the Mitsubishi process, where it accounts for 47 percent of the total.

Again, it must be emphasized that these costs are generalized, approximate values that take into account only the plant modifications required to install (retrofit) the specified process in an existing smelter. They are incremental costs for the retrofit and do not cover an entire smelting facility.

In some cases, smelter process modifications may be neither feasible nor desired. Also, no potential market for sulfuric acid or sulfur products may exist. Under these conditions, gas scrubbing may be more attractive for control of SO_2 emissions. When this is the case, steps taken to reduce leakage into the furnaces and ducts and limited process modifications to minimize off-gas flow will result in a cost saving because less gas will be treated.

The estimated control costs for a smelter producing 90,720 Mg (100,000 tons) of blister copper per year and utilizing either a limestone or a lime scrubbing system are presented in Table 39. These data show that capital costs for limestone scrubbing systems range from $47,000,000 to $52,000,000, and annual operating costs run about $20,000,000 to $21,500,000, including indirect costs [$0.27 to $0.29/kg ($0.10 to $0.13/lb) of copper]. In this case, the incremental cost per unit of copper must be added to the existing smelting cost to determine the new total smelting cost. Capital costs of the lime scrubbing system are somewhat lower than those for the limestone system, but the higher reagent cost increases the annual operating costs. In both cases, the end product is a dewatered gypsum product that is stored at the site. When one considers the approximate nature of these values, there is actually little difference in the annual operating cost per unit of copper produced.

When a recoverable sulfur product can be marketed, the annual operating cost for SO_2 control is greatly decreased. Estimated costs for controlling conventional smelters by recovering a combination of sulfuric acid and liquid SO_2 are presented in Table 40. In the first case, a citrate scrubbing system with a liquid-SO_2-recovery plant is used to treat roaster and reverberatory off-gases, and a double-contact sulfuric acid plant is used for the converter off-gases. In this case, the total capital cost is about $70,200,000 and the annual operating cost is $12,500,000, including a credit for the SO_2 and sulfuric acid. The annual operating costs are equal to approximately $0.14/kg ($0.063/lb) of blister copper produced. In the second case, a citrate scrubber and liquid SO_2 recovery system are used to process all the off-gases. This results in a capital cost of

TABLE 39. COSTS OF CONTROLLING SO_2 FROM CONVENTIONAL SMELTERS BY FLUE GAS SCRUBBING[a]

Process	Average flow, m^3/s (scfm)	% SO_2 by volume	Scrubbing medium	% SO_2 controlled[b]	Capital cost,[c] $ x 10^6	Annual operating cost,[c] $ x 10^6	Capital cost per Mg (ton) of annual capacity	Added Annualized cost per kg (lb) of copper, $
Roaster (multihearth)	33.5 (49,800)	2.5	Limestone	85	52	21.5	573 (520)	0.24 (0.11)
Reverberatory	66.7 (141,400)	1.0	Lime	90	42	26	403 (420)	0.29 (0.13)
P-S converters	31.3 (66,400)	4.0						
Total	121.5 (257,600)	2.06						
Roaster (fluid bed)	8.0 (17,000)	10.0	Limestone	85	47	20	518 (470)	0.22 (0.10)
Reverberatory	53.4 (113,000)	1.0	Lime	90	36	23	397 (360)	0.25 (0.11)
P-S converters	29.4 (62,200)	4.0						
Total	90.8 (192,300)	2.7						
Reverb (green feed)	59.0 (125,000)	1.4	Limestone	85	50	21	551 (500)	0.23 (0.10)
P-S converter	41.3 (87,600)	4.0	Lime	90	37	24	408 (370)	0.26 (0.12)
Total	100.3 (312,600)	2.5						

[a] For an existing smelter with an annual production of 90,720 Mg (100,000 tons) of blister copper. Sulfur in concentrate amounts to 102,084 Mg (112,550 tons)/yr. Total costs are shown for either a limestone or a lime system.

[b] Percent of SO_2 removed from gas stream only.

[c] Costs are in January 1983 dollars and are based on information in Section 3. Limestone $11.03/Mg ($10/ton); lime, $55.13/Mg ($50/ton).

TABLE 40. COSTS OF CONTROLLING SO_2 FROM CONVENTIONAL SMELTERS[a] - SULFURIC ACID AND SO_2 RECOVERY SYSTEMS

Process	Average flow, m^3/s (scfm)	% SO_2 by volume	Control method	% sulfur controlled[b]	Capital cost,[c] $ x 10^6	Annual operating costs,[d] $ x 10^6	Capital cost per Mg (ton) of annual capacity	Additional annual cost per kg (lb) of copper, $
Roaster (multihearth)	23.5 (49,800)	2.5	Citrate-liquid SO_2		35.6	3.1		0.034
Reverberatory furnace	66.7 (141,400)	1.0		91				
P-S converters	31.3 (66,400)	4.0	Acid plant		34.6	9.4		0.104
Total					70.2	12.5	704 (702)	0.138 (0.0625)
Roaster (multihearth)	23.5 (49,800)	2.5	Citrate-liquid SO_2					
Reverberatory furnace	66.7 (141,400)	1.0						
P-S converters	31.3 (66,400)	4.0						
Total	121.5 (257,600)	2.06		91	46.7	-2.1	467 (423)	-0.023 (-0.0105)
Roaster (fluid bed)	8.0 (17,000)	10.0	Citrate-liquid SO_2		25.0	4.3		0.047
Reverberatory furnace	53.4 (113,100)	1.0	Acid plant[e]	92	44.8	10.6		0.117
P-S converters	29.4 (62,200)	4.0						
Total					69.8	14.9	769 (698)	0.164 (0.0745)
Reverberatory furnace (green-feed)	59.0 (125,000)	1.4	Citrate-liquid SO_2	91	28.7	3.8		0.042
P-S converter	41.3 (87,600)	4.0	Acid plant		42.5	11.2		0.123
Total					71.2	15.0	785 (712)	0.169 (0.0750)

[a] For an existing smelter with an annual production of 90,720 Mg (100,000 tons) of blister copper. Sulfur in concentrate amounts to 102,084 Mg (112,550 tons) per year.

[b] Overall % of sulfur, assuming 5% is lost in slag, fugitive emissions, and acid plant blowdown. Acid plant control efficiency is more than 99%, and the efficiency of the citrate system is 95%. Total sulfur entering the plant in concentrate is 102,084 Mg (112,500 tons) per year.

[c] Costs are in January 1983 dollars.

[d] Costs are in January 1983 and are based on information in Sections 3 and 4.

[e] Acid plant serves fluid-bed roaster and Peirce-Smith converter.

$46,700,000 and, if all of the SO_2 is sold at $110.2/Mg ($100/ton), a net annual credit that could amount to about $2,100,000. The annual operating costs are equivalent to a saving of about $0.02/kg ($0.01/lb) of blister copper produced.

In the third example, a sulfuric acid plant is used to treat the fluid-bed roaster and converter off-gases and a citrate-liquid SO_2 system is used to process the reverberatory furnace off-gases. This system would cost approximately $70,000,000, and the annual operating costs would be about $15,000,000 (again, with credit for acid and liquid SO_2). The annual operating costs are equivalent to about $0.16/kg ($0.075/lb) of blister copper produced. When the off-gases from a green-feed reverberatory furnace and the converter are treated by a citrate-liquid SO_2 system and an acid plant, respectively, the costs would be similar to those in the third example.

Magnesium oxide scrubbing systems followed by either a liquid SO_2 recovery system or a sulfuric acid plant presents another option for SO_2 control. This system, however, tends to be more costly than the citrate-based system.

CONCLUSIONS

A comparison of the incremental costs for control of sulfur dioxide emissions by process change with those for the addition of flue gas scrubbing is indicative of the decisions facing the copper industry. Clearly, the approaches based on process change (ranging from $67 to $87 million) and regenerable flue gas scrubbing (about $70 million) are the most capital-intensive. The approaches based on lime/limestone scrubbing ($36 to $52 million) are much less capital-intensive. The capital costs presented for regenerable flue gas scrubbing are based on the citrate system. Although the sulfur dioxide absorption and stripping components of this system have been well demonstrated at pilot-scale levels on smelter off-gas, the system developer, Flakt, has yet to demonstrate the economics of a full-scale citrate recovery system. Also, in the case presented for citrate scrubbing with the stripped sulfur dioxide fixed as liquid sulfur dioxide, the attractive capital and annual operating costs are based on the marketability of the liquid sulfur dioxide produced. Such a market for liquid sulfur dioxide is unlikely to exist for smelters located in the southwestern United States; however, it is somewhat more likely that a greenfield smelter located near sulfite-based paper plants in the southeastern United States could tap a sufficiently large market for sulfur dioxide.

In contrast, the annual operating costs for process change [ranging from 28 to 36 cents per kilogram (13 to 16 cents per pound) of copper] would appear more attractive than approaches based on add-on flue gas scrubbing (22 to 29 cents for lime/limestone, 14 to 17 cents for citrate). This occurs because the annualized operating costs for a process change include the costs of operating the smelting furnace, whereas those for flue gas scrubbing systems are in addition to the costs for operating the smelting furnaces.

The decision then becomes one of trading off capital costs for operating costs. The trade-off analysis is difficult because of the variable price of copper, the marketability and price of the sulfur byproduct, the life of the smelter, and the cost of capital. It would be more economical to use a throwaway flue gas scrubbing system where the cost of capital is high and the life of the smelter is limited by its present condition, market viability, or security of concentrate supply. Where the life of the smelter is judged to be longer, continuous control of sulfur dioxide would be most economically achieved through process change.

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APPENDIX A

GUIDE TO THE EPA COST ESTIMATION MODEL FOR SMELTER PROCESS RETROFITS

INTRODUCTION

This appendix describes the proper procedures for accessing and using a computerized model for estimating the capital and annual operating costs of selected smelter process modifications.

The program calculates the quantities of concentrate and flux; the number and size of fluid-bed dryers; retrofitted furnaces required for INCO oxygen flash, oxygen-sprinkle, or oxygen-fuel smelting; and associated oxygen and acid plants. Their respective capital and annual operating costs with steam and/or acid credits are also calculated. The program is to be used on an IBM PC-XT with a Lotus 1-2-3 program.

The user can input variables that will allow estimates of fairly site-specific costs or utilize existing default values. Cost indices are provided for each equipment category so they can be adjusted to any year between 1970 and 1984.

DESCRIPTION OF MODEL

A flow sheet was made that shows the existing primary smelting systems and the proposed process change(s) and incorporates the corresponding emission control devices.

The following areas within the smelter were examined to determine equipment changes or modifications required by the proposed changes:

- Material storage, sizing, blending, and reclaiming operations.
- Reverberatory area: Material day storage bins and concentrate/flux feeding to the furnace or dryers, waste-heat boilers, off-gas ducting, particulate control, slag handling, matte handling, hearth area, building alterations, fuel, burners, oxygen lines, SO_2 concentrations in off-gas, instrumentation, electric overhead traveling cranes, and water requirements.

- Converter area: Number of converters, off-gas ducting, particulate control, slag reclaiming or crushing and grinding techniques, blister handling, SO_2 concentration in off-gas, blowing requirements, instrumentation, and electric overhead traveling cranes.

- Anode area: Number of anode furnaces and casting wheels, electric overhead cranes, water, and natural gas.

- Special area: Acid plant capacity, acid plant design based on flow and SO_2-concentration-handling capability, truck shipping and storage ability, acid neutralization, retrofit or new plant (if space available), oxygen plant capacity, available space, and utilities.

Discussions were held with suppliers and developers of the process changes proposed in this study to help determine equipment sizing and needs. Process flows in published reports, the literature, symposium papers, and current text books were reviewed.

Based on information gathered, the following items or areas were defined:

- Material storage, etc., were left intact; however, if the fines carryover at the primary smelting unit exceeded 2 percent of the feed, agglomeration or pelletizing was considered to minimize recirculation of these fines in the off-gas.

- Reverberatory area: No major changes were made to the day storage bins and feeding for oxy-fuel smelting, but changes were made to both INCO and oxygen-sprinkle smelting for storage and feeding to the oxygen-feed burners; fluid-bed or rotary dryers were utilized for all proposed systems to decrease the off-gas volume and heat loss in the gas; waste-heat boilers were modified for oxygen-sprinkle smelting and oxy-fuel smelting, but eliminated for the INCO; off-gas ducting and ESP(s) were changed for INCO and oxygen-sprinkle smelting because of reduced gas flow; ESP was retrofitted for oxy-fuel smelting; based on a concentrate feed per square foot of hearth area, the new INCO furnace would yield approximately 40 percent of a wet-feed reverberatory smelter; increased slagging and tapping facilities were needed for each system over the conventional wet-feed reverberatory furnace; and the oxygen-sprinkle smelting and oxy-fuel retrofitted reverbs were rebuilt to tighten the furnaces and to include suspended arches/hangers and provisions to service burners.

- Converting area: The INCO and oxygen-sprinkle smelting matte grades of 50 percent copper indicated a reduction in the number of converters to be in use as the copper in the matte grade increases because of a decrease in iron to be removed and a smaller decrease in sulfur, which in turn affect the blowing time for the slag or finish blow in the converter.

- Anode area: No changes were made because original plant design and capability were maintained.

- Special area: New double-absorption/double-contact acid plants with handling and storage facilities were used in this study. The oxygen plant size was based on 0.8 kg of oxygen per kg of copper.

Development of the equipment cost data for the major component items was based on the following:

- Material costs and estimated fabrication costs.

- Vendor-estimated costs (total finite detailed information was not available).

- Updated costs based on the appropriate Chemical Engineering index evaluation factors (see Table A-1).

- Published EPA cost studies for the nonferrous industry

- Bureau of Mines published cost data for primary copper smelting equipment.

- Estimated percentage factors for installation (simple retrofit), piping, insulation, electrical work, instrumentation, foundations, painting, miscellaneous items (platforms, stairs, etc.), battery limits and provisions for the oxygen and acid plants, engineering costs (modified for large purchased components being designed by the vendor), startup (including plant personnel and orientation programs), contractor's fee and offsite expenses, contingency, and interest during construction.

- Turnkey contracts with contingency for oxygen plants, and turnkey contracts with a minimum of 20 percent excess capacity and a contingency for acid plants. Gases from the primary smelter unit and Peirce-Smith converter were combined en route to the acid plant.

- Estimated cost of removing the existing reverberatory furnace and ducting. (The existing ESP was not used for INCO and oxygen sprinkle smelting.)

TABLE A-1. CHEMICAL ENGINEERING COST INDEX

ID Symbol		1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981[a]	1982	1983[b]	1983	1984[c]
A	CE Plant	125.7	132.3	137.2	144.1	165.4	182.4	192.1	204.1	218.8	238.7	261.1	290.1	314.0	315.5	316.6	320.3
B	Equipment, machinery, and supports	123.8	130.4	135.4	141.8	171.2	194.7	205.8	220.9	240.3	264.7	292.2	318.7	336.2	334.9	337.4	340.0
C	Fabricated equipment	122.7	130.3	136.3	142.5	170.1	192.2	200.8	216.6	238.6	261.7	291.6	317.1	326.0	324.4	328.0	331.5
D	Process machinery	122.9	127.9	132.1	137.8	160.0	184.7	197.5	211.6	228.3	250.0	271.8	296.5	312.0	319.6	318.8	327.5
E	Pumps and compressors	125.6	133.2	135.9	139.8	175.7	208.3	220.9	240.2	257.5	280.4	330.3	381.8	412.2	416.6	410.6	409.1
F	Construction labor	137.3	146.2	152.2	157.9	163.3	168.6	174.2	178.2	185.9	194.9	204.3	232.3	263.9	268.9	265.6	267.7
								Marshall and Swift Indexes									
		1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984[d]	
G		303.3	321.3	332.1	344.1	398.4	444.3	472.1	505.4	545.3	599.4	659.6	721.3	745.6	760.8	770.8	

[a] Calculated for January-July 1981. These values are the basis for the cost model.
[b] January 1983.
[c] January 1984.
[d] 1st quarter 1984.

- Other adjustment factors included the following:
  - Size: Published literature (Guthrie,[1] McGlammery,[2] and PEI calculated costs for two or more sizes or capacities of equipment).
  - Year: Chemical Engineering Plant Cost Index (the most appropriate subdivision).
  - Engineering: Basically 15 percent for design; since many items are purchased with minimal engineering, 10 percent was selected.
  - Instrumentation: Turnkey items include instrumentation, but new equipment and tie-ins to existing updated equipment were estimated.
  - Electrical work: The plant had sufficient capacity to accommodate the retrofitted equipment; if there is an existing single-absorption/single-contact acid plant, the new larger double-absorption/double-contact plant would have sufficient electrical power available.
  - Contingency: 25 percent for the smelter proper, 10 percent for the oxygen plant, and 12.5 percent for the acid plant.

Operating cost data were generated from published literature by Kellogg and Henderson,[3] Pitt and Wadsworth,[4] Bureau of Mines,[5] INCO Metals Company,[6] Chemical Marketing Reporter,[7] Queneau and Schuhmann,[8] Teniente Mining Division (CODELCO-CHILE),[9] and PEI in-house data.

The following factors were used in developing the cost estimates:

- In all instances, a 4 percent SO_2 by volume was used for Peirce-Smith converter off-gases.
- Excess steam not required for preheat air, fuel, or other plant uses was used for electricity at 14,500 Btu per kWh, and credited at 40 mills per kWh.
- Cooling water cost was based on pumping a 90-foot head.
- Depreciation was on a straight-line basis per IRS Publication 534, revised November, 1982. Oxygen and acid plant levels of 9.5 years and a smelter-proper retrofit life of 14 years were used.

- Interest was assumed to be 10 percent.

- To predict the capital cost for a future year, the following multipliers were utilized. These multipliers are based on the past 5 years of the Chemical Engineering Plant Cost Indexes (through January 1984).

C.E. Plant	1.061^x
Equipment, machinery, and supports	1.051^x
Fabricated equipment	1.048^x
Process machinery	1.055^x
Pumps and compressors	1.078^x
Construction labor	1.066^x

where "x" is in years.

Tables A-2 and A-3 summarize the capital and annual operating cost factors for the computerized cost model.

PROGRAM INPUT AND OUTPUT

Input is from a keyboard with defaults provided for all input variables. When inputs are unknown, suggested inputs are available. Costs can be determined from 1970 to the present and can also be escalated into the future.

Output is to an ASCII file intended for use with Lotus 1-2-3. The format of the output file name is: "user filename" plus "3 character retrofit type code" plus ".PRN'. A "debug" file with all major intermediate calculations is also generated. Both of these files are read by use of the 1-2-3 "import" command.

The data input required or selected from the suggested data input are:

- Composition in percentage by weight of the copper, sulfur, and iron in the concentrate

- Mg/year of anode copper production

- Percent by weight copper in matte

- Percent sulfur from primary retrofit furnace smelting (i.e., INCO or oxygen-sprinkle or oxy-fuel)

- Percent sulfur from Peirce-Smith (P-S) converters

- Percent sulfur by volume in off-gas from primary retrofit furnace

TABLE A-2. CAPITAL COST BASIS FOR SMELTER MODIFICATION

		Factor	Reference
1.	Equipment cost - F.O.B. job site Rotary dryers, ESP, dust-removal screw conveyors, modified reverb. furnace with waste-heat boilers and ancillaries, ducting, hot ESP(s), hood for launders and ladles at furnace, etc.	-	Vendor quotes and Bureau of Mines estimates. A factor exponent was used to vary equipment cost for different sizes and types of equipment.
2.	Installation	0.456	A weighted factor for the various types of equipment involved.
3.	Piping, insulation	0.084	
4.	Electrical, instrumentation	0.081	
5.	Foundations, painting, misc.	0.048	
6.	Structural building alterations		Specific cost estimate.
7.	Site clearance - remove existing reverb, ductwork		
8.	Turnkey - oxygen plant		Vendor quote
9.	Turnkey - acid plant (1066 Mg/per day acid plant for 90,720 Mg/year)		Costs based on data from T. J. Browder.
10.	Misc. - battery limits for Items 8 and 9	0.009	Estimated.
11.	Equipment costs (installed)		Total of 1 to 10.
12.	Engineering	0.10	Estimated, based on limited modifications involved.
13.	Startup	0.035	Estimated.
22.	Contractor's fee and offsite expense	0.05	Estimated.
23.	Contingency	0.25	
24.	Interest during construction	0.105	Estimated based on the equivalent of 2½ years to design and install.

TABLE A-3. ANNUAL OPERATING COST BASIS FOR SMELTER MODIFICATION

	Unit	Units/yr	$/unit	Reference
51. Raw materials - lime	0.907 Mg (tons)		40.00	
56. Direct labor	Hours		10.00	
57. Supervision	15%	Direct labor	10.00	
58. Maintenance labor	1.875%	Installed cost	-	
59. Maintenance supervision	20%	Maintenance labor	-	PEI estimate based on Bureau of Mines guidelines
60. Maintenance materials	2%	Installed cost	-	
61. Operating supplies	20%	Plant maintenance	-	
62. Payroll overhead	60%	Labor and supervision	-	
63. Electricity	kWh		0.04	
64. Coal and oil	0.907 Mg (tons) 3.785 liters (gal)		35.00 1.00	Estimated, based on industrial fuel rates
65. Natural gas	28.3 m³ (1000 ft³)		2.50	
66. Water - process	3785 liters (1000/gal)		0.34	
67. Water - cooling	3785 liters (1000/gal)		0.06	PEI estimate
71. Administration and overhead	40%	Labor, supervision, materials, and supplies	-	
76. Taxes and insurance	2%	Installed cost	-	
78. Depreciation (straight-line)				
Acid and oxygen plant	10.526%	Acid and oxygen plant related costs		
Smelting	7.143%	Smelter related costs		Internal Revenue Service depreciation guidelines
79. Cost of funds or interest	10.00%	Total plant cost		Estimate based on industrial bond rates
80. Total operating cost				
82. Byproduct credit - H_2SO_4	0.907 Mg (tons)		20.00	Chemical Marketing Reporter, S.W. U.S.
83. Byproduct credit - steam	kWh		0.04	Estimated

- Percent sulfur by volume in off-gas from P-S converters
- Percent sulfur in coal
- Percent copper in concentrate input to anode copper
- Percent oxygen purity from oxygen plant
- Percent oxygen efficiency utilization
- Acid plant overdesign capacity as a percentage
- Kilograms oxygen per kilogram copper
- Percent flux added to concentrate
- Operating days per year at rated operating capacity
- Chemical Engineering and Marshall and Swift Cost Indexes for plants
- Cost of electricity per kWh
- Cost of processing and cooling water per 1000 liters
- Raw material costs per megagram for lime and coal
- Cost for natural gas per cubic meter and oil per liter
- Labor costs
- Rate for taxes and insurance as a percentage of capital installed cost
- Number of years for depreciation of acid plant, oxygen plant, and retrofitted smelter proper as a percentage of their respective installed capital costs
- Excess steam credit per kilo-calories converted to electrical kWh
- Cost of neutralization per ton of acid
- Interest
- Type of retrofit for each segment - easy, moderate, or extremely difficult
- Installation assumed not to interfere with production

The output cost data can be printed, plotted as graphs, or displayed as bar or circle charts of one retrofit system for two or more different sized plants or for a comparison of all of the systems for a specified size plant. The following individual items can be generated.

- Capital costs - total plant costs vs. megagrams of anode copper per year
- Annual operating costs vs. megagrams/year with steam credits, steam and acid credits, or acid credits
- Costs per kilogram copper vs. megagrams of anode copper per year
- A printout showing costs and number of furnaces or fluid-bed dryers or acid plants
- Acid plant costs with 5-day storage and shipping facilities for a new or add-on acid plant and its operating cost
- Oxygen plant installed capital and annual operating costs

User's warning:

- When generating annual operating smelter costs, both the acid and oxygen plant costs are included. If only the basic smelter cost is wanted, it is possible to determine the acid and oxygen plant costs and manually deduct them from the total smelter costs.
- The program generates costs for designed capacity and does not have the capability to handle utilization factors of less than 100 percent.
- The program currently does not permit the calculation of the operating break-even point.
- When an add-on acid plant is utilized, the program shows the cost of the add-on portion and the capacity of H_2SO_4 in megagrams/day.
- Other furnace retrofits using Noranda, Outokumpu Oy, Mitsubishi continuous, and other possible retrofit systems are not included.
- If the iron content changes by more than ±2 percent of the suggested input value, the flux intput should also be adjusted.

- Annual operating costs take into account savings generated as the percent of copper in the matte increases for the Peirce-Smith converters.

PROGRAM LISTING

An example printout and complete program listing are presented in the balance of this appendix.

```
Example Copter Output


        Current Date                            08-31-1984      08-31-1984      08-31-1984
        Furnace Type Retrofit                   INCO            Oxygen Sprinkle Oxy-Fuel
        Mg/year copper, anode                           90,685          89,700          90,685
        Mg/day concentrate and flux                    1139.39         1139.37         1174.09
        Mg/day H2SO4 in Acid Plant                      780.12          765.61          760.76
        Ore Analysis
           % Copper                                      0.295           0.295           0.295
           % Sulfur                                      0.310           0.310           0.310
           % Iron                                        0.290           0.290           0.290
        % SO2 by volume in offgas                        0.800           0.260           0.080
        Retrofit factor                         Easy            Easy            Easy
        Retrofit multiplier                                  1               1               1
        Year of Costs                                       84              84              84

DIRECTS :
       1 Equipment Cost - F.O.B. Job Site          5,404,359       6,066,381       6,125,799
       2 Installation                              2,464,388       2,772,336       2,805,616
       3 Piping and Insulation                       660,975         742,452         750,239
       4 Electrical and Instrumentation              637,368         715,936         732,376
       5 Foundations, Painting, Misc.                377,700         433,097         446,571
       6 Structural Building Alterations             140,190         140,190         140,190
       7 Site Clearance                              560,761         560,761         560,761
       8 Turnkey Oxygen Plant                      9,814,345       9,814,345       9,814,345
       9 Turnkey Acid Plant                       38,857,104      40,955,120      49,747,624
      10 Misc. battery limits                        438,043         456,925         575,995

      11 Equipment Costs (installed)              59,355,233      62,657,545      71,652,515

INDIRECTS :
      12 Engineering                               1,066,378       1,188,808       1,209,755
      13 Start-up                                    373,932         416,083         423,414
      22 Contractor's Fee                            552,886         615,208         626,048
      23 Contingency                               3,169,745       3,527,044       3,599,191
      24 Interest during construction              6,774,618       7,182,492       8,137,591
      30 Total Indirects Cost                     11,939,559      12,929,635      13,986,004

      31 TOTAL PLANT COSTS                       $71,294,792     $75,587,180     $85,638,519


ANNUAL OPERATING COSTS :
      51 Raw Materials - lime                        361,154         356,287         352,191
      56 Direct labor                              2,475,214       2,783,282       2,787,122
      57 Supervision                                 371,282         417,492         418,068
      58 Maintenance Labor                         1,336,777       1,417,260       1,605,722
      59 Maintenance Supervision                     267,355         283,452         321,144
      60 Maintenance Materials                     1,425,896       1,511,744       1,712,770
      61 Operating Supplies                          606,006         642,491         727,927
      62 Payroll Overhead                          2,670,377       2,940,891       3,079,234
      63 Electricity                               3,701,707       3,828,284       2,678,459
      64 Fossil Fuel                                 828,233       1,228,351       5,204,770
      65 Natural Gas                                  30,001          30,001          46,377
      66 Water, Process                               25,267          23,077          25,260
```

Example Copter Output

```
67 Water, General                              1,895         2,010         1,894
71 Administration and Overhead             2,593,012     2,822,289     3,029,102
76 Taxes and Insurance                     1,425,896     1,511,744     1,712,770
78 Depreciation  A. Acid Plant             4,519,559     4,763,584     5,785,447
                 B. Oxygen Plant           1,141,529     1,141,529     1,141,529
                 C. Smelting               1,250,942     1,391,951     1,416,477
79 Cost of funds or interest               7,129,479     7,558,718     8,563,851

80 ANNUAL OPERATING COSTS -no credits    $32,161,583   $34,654,434   $40,610,113

82 Acid Credits                          (5,807,250)   (5,728,981)   (5,663,134)

83 Steam Credits                                   0     (556,058)   (1,038,345)

90 Annual Oper. Costs w/ Acid Credits     26,354,333    28,925,454    34,946,979

91 Annual Oper. Costs w/Steam Credits     32,161,583    34,098,376    39,571,768

92 Annual Oper. Costs w Acid & Steam      26,354,333    28,369,396    33,908,634


100 $/kg copper w/ acid & steam credit         0.291         0.316         0.374

101 $/kg copper w/ steam credit                0.355         0.380         0.436

102 $/kg copper w/steam credit and             0.435         0.461         0.511
    neutralize all acid produced
```

```
10 ' ***********************************************************
20 ' *                        COPTER                           *
30 ' *        Primary Copper Smelter Retrofit Program          *
40 ' * Written by PEI, Inc. (jp,jw)              August, 1984 *
50 ' *                                                         *
60 ' ***********************************************************
70 '     This program calculates sizing and costs for the con-
80 ' version of a primary copper smelter from a Wet-Feed or
90 ' Dried-Feed Reverberatory Furnace to INCO, Oxygen Sprinkle,
100 ' or Oxy-Fuel smelting. Input is from keyboard with defaults
110 ' provided for all input variables. Output is to an ascii file
120 ' intended for use with Lotus 1-2-3. The format of the output
130 ' file name is :
140 '     "user filename"+"3 char. retrofit type code"+".PRN"
150 ' A "debug" file with all major intermediate calculations is also
160 ' generated. Both of these files are read using the 1-2-3 "import
"

170 ' command.
180 '
190 ' >>> Initialization <<<
195 KEY OFF
197 DEFDBL C
200 DIM DIT(30,5),DIT$(30,5),DF(30,5,3),DET(50,20),TB(15,5),TB$(15,5)
,BU$(15,5),
TA(7,16),COSTS(110,5),UB(15),NOBREAK(20)
205 DATA INC,OXS,OXF
207 FOR I%=1 TO 3:READ RETEXT$(I%):NEXT I%
210 ' >> Read Input Table Descriptions and Defaults <<
220 READ DIT(0,0):FOR I%= 1 TO DIT(0,0):READ DIT(I%,0):FOR J%=1 TO DI
T(I%,0):REA
D DIT$(I%,J%):FOR K%=1 TO 3:READ DF(I%,J%,K%):NEXT:NEXT:NEXT
240 DATA 27,3,% Copper in concentrate,29.5,29.5,29.5,% Sulfur in conc
entrate,31,
31,31,% Iron in concentrate,29,29,29
250 DATA 1,Mg/year copper - anode,90685,89700,90685,1,% Copper in mat
te,50,50,42
,1,% Sulfur from primary smelting,53.6,52.6,40.,1,% Sulfur in slag(di
scard),.7,.
8,2,1,% Sulfur from primary (fugitives),.7,1,1.4,1,% Sulfur from P-S
converters,
43,42.7,54.3
270 DATA 1,% Sulfur in P-S slag - return to primary,.6,.6,1.9,1,% Sul
fur from P-
S (fugitves),.7,.7,1.3,1,% SO2 by volume from primary,80,26,8,1,% SO2
 by volume
from P-S,4,4,4,1,Ppm SO2 by volume from dc/da acid plant tail gas,500
,500,500
280 DATA 1,% Sulfur  in sludge from acid plant,2,2,2,1,% Fines from p
```

```
rimary,2,3,
2,1,% Sulfur in coal,0,2,0,1,% Copper in concentrate to cathode coppe
r,96.81,95.
76,96.81,1,% Flux in concentrate,8.8,8.8,8.8,1,% Flux added to concen
trate,4.7,4
.7,8
290 DATA 1,Days/year full operation,350,350,350,1,% Copper in concent
rate to ano
de copper,96.85,95.8,96.95,1,% Moisture in concentrate and flux,8,8,8
,1,% Oxygen
 purity,95,95,95,1,% Oxygen utilization efficiency,95,95,95
300 DATA 1,Acid plant capacity oversize,22,22,22,1,Kg oxygen/Kg coppe
r,.8,.8,.82
,1,Retrofit Factor,1,1,1,1,Year of Costs,84,84,84
310 ' >> Read "Table B" Factors and Units <<
320 READ TB(0,0):FOR I%=1 TO TB(0,0):READ UB(I%):FOR J%=0 TO UB(I%):R
EAD TB$(I%,
J%),TB(I%,J%),BU$(I%,J%):NEXT:NEXT
330 DATA 12,3,Utilities,0,0,Electric,.04,KWH,Water (processing),.09,1
000 liters,
Water (cooling),.016,1000 liters
340 DATA 5,Raw materials and Fuels,0,0,Lime,44.09,Mg,Coal,34.6,Mg,Oil
,.2642,lite
r,Natural gas,.0883,nM3,Caustic soda,90.,Mg
350 DATA 2,Operation,0,0,Operators,10,operator hours,Operator supervi
sion,15,% o
perator hours
360 DATA 3,Maintenance,0,0,Maintenance personnel,1.875,% capital cost
,Supervisio
n,20,% maintenance personnel,Materials,2,% capital cost
370 DATA 1,Payroll and Overhead,0,0,Payroll and Overhead,60,% Operati
ng and Main
tenance Labor
380 DATA 1,Supplies,0,0,Supplies (operating),20,% maintenance
390 DATA 1,Administration and Overhead,0,0,Administration and Overhea
d,40,% oper
ation+maintenance+supplies
400 DATA 1,Taxes and Insurance,0,0,Taxes and Insurance,2,% capital co
st
410 DATA 4,Depreciation (straight line),0,0,Oxygen plant,10.526,oxyge
n plant cap
ital cost,acid plant,10.526,acid plant capital cost,Smelter retrofit,
7.143,retro
fit capital cost,Storage and shipping facilities,7.143,s&s capital co
st
420 DATA 1,Neutralization of Acid with Lime,0,0,Neutralization of Aci
d with Lime
,25.19,Mg of acid
```

```
430 DATA 1,Cost of Funds or Interest,0,0,Cost of Funds or Interest,10
,% capital
cost
440 DATA 2,Credits,0,0,Steam,.04,KWH,H2SO4,22.04,Mg of acid
450 ' >> Read "Table A" Escalation Indices <<
460 FOR I%=1 TO 7:FOR J%=1 TO 15:READ TA(I%,J%):NEXT:NEXT
465 ' > CE plant indices <
470 DATA 125.7,132.3,137.2,144.1,165.4,182.4,192.1,204.1,218.8,238.7,
261.1,290.1
,314.0,316.6,320.3
476 ' > Equpment, machinery, and supports indices <
480 DATA 123.8,130.4,135.4,141.8,171.2,195.7,205.8,220.9,240.3,264.7,
292.2,318.7
,336.2,337.4,340.0
486 ' > Fabricated equpment indices <
490 DATA 122.7,130.3,136.3,142.5,170.1,192.2,200.8,216.6,238.6,261.7,
291.6,317.1
,326.0,328.0,331.5
496 ' > Process machinery indices <
500 DATA 122.9,127.9,132.1,137.8,160.0,184.7,197.5,211.6,228.3,250.0,
271.8,296.5
,312.0,318.8,327.5
506 ' > Pumps and compressors indices <
510 DATA 125.6,133.2,135.9,139.8,175.7,208.3,220.9,240.2,257.5,280.4,
330.3,381.8
,412.2,410.6,409.1
516 ' > Construction labor indices <
520 DATA 137.2,146.2,152.2,157.9,163.3,168.6,174.2,178.2,185.9,194.9,
204.3,232.3
,263.9,265.6,267.7
526 ' > Marshall & Swift indices <
530 DATA 303.3,321.3,332.1,344.1,398.4,444.3,472.1,505.4,545.3,599.4,
659.6,721.3
,745.6,760.8,770.8
540 ' > Append superscripts <
550 FOR I%=4 TO 9:IF I% <> 7 THEN DIT$(I%,1)=DIT$(I%,1)+CHR$(248)
560 NEXT:DIT$(13,1)=DIT$(13,1)+CHR$(248):DIT$(12,1)=DIT$(12,1)+CHR$(2
54)
600 ' >>> User Input Section <<<
610 CLS:COLOR 0,7:PRINT STRING$(37," ");"COPTER";STRING$(37," "):COLO
R 7,0:LOCAT
E 11,20,1: PRINT "Please select retrofit type furnace:":PRINT TAB(30)
 "1. INCO";
PRINT TAB(30) "2. Oxygen sprinkle smelting":PRINT TAB(30) "3. Oxygen
fuel smelti
ng"
620 PRINT:PRINT TAB(20) "Enter the number of your selection>";
630 K$=INKEY$:IF VAL(K$)<1 OR VAL(K$)>3 THEN 630
```

```
640 DET(1,1)=VAL(K$)
642 ' > Set defaults for input table <
643 FOR I%=1 TO DIT(0,0):FOR J%=1 TO DIT(I%,0):DIT(I%,J%)=DF(I%,J%,DE
T(1,1)):NEX
T :NEXT
645 ON ERROR GOTO 0
647 CLS:COLOR 0,7:PRINT STRING$(37," ");"COPTER";STRING$(37," "):COLO
R 7,0
650 LOCATE 12,21:PRINT "Please enter the name of your input file>":PR
INT:PRINT "
This can be up to 5 alphabetic characters. (If you don't have an inpu
t file, you
should still enter a name; the program will create the file for you.)
"
660 LOCATE 12,62:LINE INPUT ; INFILE$:X= LEN(INFILE$):IF X > 5 THEN B
EEP:GOTO 65
0
670 ON ERROR GOTO 20000:OPEN INFILE$+RETEXT$(DET(1,1))+".inp" FOR INP
UT AS #1:IN
PUT#1,DIT(0,0):FOR I%=1 TO DIT(0,0):INPUT#1,DIT(I%,0):FOR J%= 1 TO DI
T(I%,0):INP
UT#1,DIT(I%,J%):NEXT:NEXT
680 INPUT#1,TB(0,0):FOR I%=1 TO TB(0,0):INPUT#1,UB(I%):FOR J%=0 TO UB
(I%):INPUT#
1,TB(I%,J%):NEXT:NEXT:CLOSE #1:ON ERROR GOTO 0
700  ' >> Data Input Table Entry <<
705 ON ERROR GOTO 0
710 IO%=1:JO%=1 ' initalize dit table pointers
712 WHILE IO%<> DIT(0,0) OR JO%<>DIT(DIT(0,0),0)' loop on dit table p
ointers
715 GOSUB 800:LINES%=0 ' display dit table
720 J2%=J1%:FOR I%=I1% TO DIT(0,0):FOR J%= J1% TO DIT(I%,0):J1%=1:LIN
ES%=LINES%+
1 ' step through table beginning w/ update pointer; increment screen
line counte
r
725 IF I%>25 THEN LOCATE LINES%+2,1:COLOR 0,7:PRINT USING "&";DIT$(I%
,J%);:LOCAT
E ,70:PRINT USING "##########";DIT(I%,J%);:COLOR 7,0:GOTO 740 ' emphas
ise current
 dit entry
730 LOCATE LINES%+2,1:COLOR 0,7:PRINT USING "&";DIT$(I%,J%);:LOCATE ,
70:PRINT US
ING "######.##";DIT(I%,J%);:COLOR 7,0 ' emphasise current dit entry
740 X%=70:Y%=LINES%+2:MC%=9:COLOR 0,7:GOSUB 10000:COLOR 7,0:IF C%>0 T
HEN DIT(I%,
J%)=VAL(S$) ' get new entry, or <cr> if same
742 IF I%>25 THEN LOCATE ,1:PRINT USING "&";DIT$(I%,J%);:LOCATE ,70:P
```

```
RINT USING
"##########";DIT(I%,J%);:GOTO 750 ' line back to normal intensity
745 LOCATE ,1:PRINT USING "&";DIT$(I%,J%);:LOCATE ,70:PRINT USING "##
####.##";DI
T(I%,J%); ' line back to normal intensity
750 IF LINES%=NLP% THEN LINES%=0:J%=DIT(I%,0):I%=DIT(0,0):J1%=J2% ' i
f bottom of
 page, rest line counter and force FOR loop to end
760 IF C%<0 THEN J%=DIT(I%,0):I%=DIT(0,0) ' if ESC, force FOR loop to
 end
770 NEXT:NEXT:IF C%>=0 THEN 720 ' if bottom of page (no ESC),restart
page loop
780 WEND:GOTO 900 ' end table loop
800 ' >> Display Data Input Table <<
803 CLS :COLOR 0,7 :PRINT STRING$(37," ");"COPTER";STRING$(36," ");:C
OLOR 7,0
805 COLOR 1:PRINT TAB(5) "Input Item" TAB(67) "Current Value":COLOR 7
 ' print he
ader
810 I1%=I0%:J1%=J0%:LINES%=0:FOR I%=I0% TO DIT(0,0):FOR J%=J0% TO DIT
(I%,0):LINE
S%=LINES%+1:J0%=1 ' set update pointers to top of page, loop on entri
es for this
 page, increment screen line counter, reset dit pointer for inner loo
p
820 IF LINES% > 20 THEN I0%=I%:J0%=J%:J%=DIT(I%,0):I%=DIT(0,0):GOTO 8
50 ' if end
 of page, set dit pointers to next page, force FOR loop to end
825 IF I%>25 THEN PRINT USING "&";DIT$(I%,J%);:PRINT TAB(70);:PRINT U
SING "#####
####";DIT(I%,J%):GOTO 840
830 PRINT USING "&";DIT$(I%,J%);:PRINT TAB(70):PRINT USING "######.##
";DIT(I%,J%
) ' print dit title and entry
840 NLP%=LINES% ' total lines in page, not 20 only at end of table
850 NEXT:NEXT:IF LINES%<20 THEN I0%=DIT(0,0):J0%=DIT(I0%,0) ' end dis
play loop,
reset table pointers if end of page
853 LOCATE 23,12:PRINT CHR$(248);" based on sulfur input in concentra
te":PRINT T
AB(12);CHR$(254)" if single contact/single absorbtion use 2500 ppm";
856 LOCATE 25,30:COLOR 0,7:PRINT "Hit Esc to continue";:COLOR 7,0
860 RETURN
900 ' >> Table 'B' Entry <<
902 IF DIT(27,1)>84 THEN TEMPYEAR=DIT(27,1)-84
904 FOR I%=1 TO 2:FOR J%=1 TO UB(I%):TB(I%,J%)=TB(I%,J%)*1.08^TEMPYEA
R:NEXT J%:N
EXT I%
```

```
906 TB(3,1)=TB(3,1)*1.08^TEMPYEAR:TB(10,1)=TB(10,1)*1.08^TEMPYEAR
908 FOR I%=1 TO 2:TB(13,I%)=TB(13,I%)*1.08^TEMPYEAR:NEXT I%
910 I0%=1:J0%=1
912 WHILE I0%<>TB(0,0) OR J0% <> UB(TB(0,0))
915 GOSUB 1100:LINES%=0
920 J2%=J1%:FOR I%=I1% TO TB(0,0):FOR J%=J1% TO UB(I%):LINES%=LINES%+
1:J1%=1
930 LOCATE LINES%+2,1:COLOR 0,7:PRINT USING "&";TB$(I%,J%);:LOCATE ,3
5:PRINT USI
NG "######.##";TB(I%,J%);:COLOR 7,0
940 X%=35:Y%=LINES%+2:MC%=9:COLOR 0,7:GOSUB 10000:COLOR 7,0:IF C%>0 T
HEN TB(I%,J
%)=VAL(S$)
945 LOCATE ,1:PRINT USING "&";TB$(I%,J%);:LOCATE ,35:PRINT USING "###
###.##";TB(
I%,J%)
950 IF LINES%=NLP% THEN LINES%=0:J%=UB(I%):I%=TB(0,0):J1%=J2%
960 IF C%<0 THEN J%=UB(I%):I%=TB(0,0)
970 NEXT:NEXT:IF C%>=0 THEN 920
980 WEND
1000 YEAR=DIT(27,1)-69
1010 IF YEAR>15 THEN YEAR=16 ELSE 1045
1020 FOR I%=1 TO 7
1030 TA(I%,YEAR)=TA(I%,15)*1.08^(DIT(27,1)-84)
1040 NEXT I%
1045 FOR I%=1 TO 7:READ TA$(I%):NEXT I%
1050 CLS :COLOR 0,7 :PRINT STRING$(37," ");"COPTER";STRING$(36," ");:
COLOR 7,0
1055 LOCATE 4,20:PRINT "Hit <return> to keep existing value"
1060 FOR I%=1 TO 7:LOCATE 8+I%:PRINT "The ";TA$(I%);" index is ";TA(I
%,YEAR);" C
hange to";:INPUT " ";NW$:NW=VAL(NW$)
1070 IF NW<>0 THEN TA(I%,YEAR)=NW
1080 NEXT I%
1090 LOCATE 20,20:INPUT "Are above values correct (Y/N)";A$:IF A$="Y"
 OR A$="y"
THEN 1200 ELSE IF A$="N" OR A$="n" THEN 1050 ELSE GOTO 1090
1095 DATA "CE Plant","Equipment, machinery, and supports","Fabricated
 equipment"
,"Process machinery","Pumps and compressors","Construction labor","Ma
rshall & Sw
ift"
1100 ' >> Display Table 'B' Data <<
1103 CLS :COLOR 0,7 :PRINT STRING$(37," ");"COPTER";STRING$(36," ");:
COLOR 7,0
1105 COLOR 1:PRINT TAB(5) "Input Item" TAB(32) "Current Value" TAB(59
) "Units
":COLOR 7 ' print header
```

```
1107 I%=0
1110 I1%=I0%:J1%=J0%:LINES%=0:FOR I%=I0% TO TB(0,0):FOR J%=J0% TO UB(
I%):LINES%=
LINES%+1:J0%=1 ' set update pointers to top of page, loop on entries
for this pa
ge, increment screen line counter, reset dit pointer for inner loop
1120 IF LINES% > 20 THEN I0%=I%:J0%=J%:J%=UB(I%):I%=TB(0,0):GOTO 1150
 ' if end o
f page, set dit pointers to next page, force FOR loop to end
1130 PRINT USING "&";TB$(I%,J%);:PRINT TAB(35):PRINT USING "######.##
";TB(I%,J%)
;:PRINT TAB(47) BU$(I%,J%)
1140 NLP%=LINES% ' total lines in page, not 20 only at end of table
1150 NEXT:NEXT:IF LINES%<20 THEN I0%=TB(0,0):J0%=UB(I0%) ' end displa
y loop, res
et table pointers if end of page
1156 LOCATE 25,30:COLOR 0,7:PRINT "Hit Esc to continue";:COLOR 7,0
1160 RETURN
1200 ON ERROR GOTO 20000:OPEN INFILE$+RETEXT$(DET(1,1))+".inp" FOR OU
TPUT AS #1:
PRINT#1,DIT(0,0):FOR I%=1 TO DIT(0,0):PRINT#1,DIT(I%,0):FOR J%= 1 TO
DIT(I%,0):P
RINT#1,DIT(I%,J%):NEXT:NEXT
1210 PRINT#1,TB(0,0):FOR I%=1 TO TB(0,0):PRINT#1,UB(I%):FOR J%=0 TO U
B(I%):PRINT
#1,TB(I%,J%):NEXT:NEXT:CLOSE #1:ON ERROR GOTO 0
1500 CLS :COLOR 0,7 :PRINT STRING$(37," ");"COPTER";STRING$(36," ");:
COLOR 7,0
1510 LOCATE 13,20:PRINT "Is this a  1) New plant":PRINT TAB(24) "or a
n  2) Exist
ing plant add-on >";
1520 A$=INPUT$(1):PRINT A$;:EX=VAL(A$):IF EX<1 OR EX>2 THEN GOTO 1500
1530 CLS :COLOR 0,7 :PRINT STRING$(37," ");"COPTER";STRING$(36," ");:
COLOR 7,0
1540 LOCATE 13,10:PRINT "Will the acid plant have  1) Single Contact/
Single Abso
rption":PRINT TAB(32) "or  2) Double Contact/Double Absorption >";
1550 A$=INPUT$(1):PRINT A$;:PT=VAL(A$):IF PT<1 OR PT>2 THEN GOTO 1530
1560 IF EX=1 THEN 1900
1570 CLS :COLOR 0,7 :PRINT STRING$(37," ");"COPTER";STRING$(36," ");:
COLOR 7,0
1580 LOCATE 13,20:INPUT "What is the existing plant capacity";PC
1590 CLS :COLOR 0,7 :PRINT STRING$(37," ");"COPTER";STRING$(36," ");:
COLOR 7,0
1600 LOCATE 13,20:INPUT "What is the existing design SO2 strength";PS
1610 CLS :COLOR 0,7 :PRINT STRING$(37," ");"COPTER";STRING$(36," ");:
COLOR 7,0
1620 LOCATE 13,7:INPUT "What is the total existing acid plant storage
```

```
 capacity";
SC
1900 CLS :COLOR 0,7 :PRINT STRING$(37," ");"COPTER";STRING$(36," ");:
COLOR 7,0
1910 LOCATE 10,15:PRINT "The following costing options are available
:":PRINT :P
RINT TAB(20) "1.  Print Total System Costs":PRINT TAB(20) "2.  Print
Acid Plant
Costs Only":PRINT TAB(20) "3.  Print Oxygen Plant Costs Only"
1920 PRINT TAB(20) "4.  Print Acid Plant and Oxygen Plant Costs Only"
:PRINT :PRI
NT TAB(15) "Input the number of your choice  >";
1930 A$=INPUT$(1):Q=VAL(A$):IF Q<1 OR Q>4 THEN 1900
1940 IF Q>2 THEN OP=1
1950 IF Q=2 OR Q=4 THEN AP=1
1960 CLS :COLOR 0,7 :PRINT STRING$(37," ");"COPTER";STRING$(36," ");:
COLOR 7,0
1970 LOCATE 12,20:PRINT "The current date is ";DATE$:PRINT TAB(20);:I
NPUT "Is th
is correct (Y/N)";A$:IF A$="Y" OR A$="y" THEN 1990
1980 PRINT TAB(20);:INPUT "New month (1-12)";X1$:X1=VAL(X1$):IF X1<1
OR X1>12 TH
EN 1980
1982 PRINT TAB(20);:INPUT "New day (1-31)";X2$:X2=VAL(X2$):IF X2<1 OR
 X2>31 THEN
 1982
1984 PRINT TAB(20);:INPUT "New year (80-99)";X3$:X3=VAL(X3$):IF X3<80
 OR X3>99 T
HEN 1984
1986 DATE$=X1$+"-"+X2$+"-"+X3$
1990 OPEN "o",1,"\123files\"+INFILE$+RETEXT$(DET(1,1))+".prn"
2000 FOR I%=1 TO 3:DIT(1,I%)=DIT(1,I%)/100:NEXT
2010 FOR I%=3 TO 11:DIT(I%,1)=DIT(I%,1)/100:NEXT
2020 FOR I%=13 TO 18:DIT(I%,1)=DIT(I%,1)/100:NEXT
2030 FOR I%=20 TO 24:DIT(I%,1)=DIT(I%,1)/100:NEXT
2050 RET=1:IF DIT(26,1)=2 THEN RET=1.5 ELSE IF DIT(26,1)=3 THEN RET=2
2060 TB(3,2)=TB(3,2)/100:FOR I%=4 TO 9:FOR J%=1 TO 4:TB(I%,J%)=TB(I%,
J%)/100:NEX
T J%:NEXT I%:TB(11,1)=TB(11,1)/100
2100 CLS: LOCATE 10,20:PRINT "Calculating ...."
2300 IF DET(1,1)=1 THEN DET(3,1)=2000' maximum capacity of concentrat
e & flux fo
r INCO furnace
2310 IF DET(1,1)=2 THEN DET(3,1)=1750 ' maximum capacity of concentra
te & flux f
or Oxygen sprinkle furnace
2320 IF DET(1,1)=3 THEN DET(3,1)=1500 ' maximum capacity of concentra
te & flux f
```

```
or Oxy-fuel furnace
2400 DET(4,1)=DIT(2,1)*(1+DIT(18,1))/(DIT(1,1)*DIT(20,1))*1.2/DIT(19,
1) ' Mg/day
 of concentrate & flux
2410 DET(4,2)=DET(4,1)/DET(3,1) ' Number of furnaces
2420 IF DET(4,2)<1 THEN DET(4,2)=1:GOTO 2450 ' if number of furnaces
is less tha
n 1 then set number of furnaces to 1
2440 DET(4,2)=INT(DET(4,2))+1 'round to largest integer for number of
 furnaces
2450 DET(4,3)=DET(4,1)/DET(4,2) ' Mg/day of concentrate & flux per fu
rnace
2500 DET(5,1)=1000 ' maximum capacity of concentrate & flux per dryer
2510 DET(5,2)=DET(4,1)*1.2/DET(5,1) ' number of fluid bed dryers
2520 IF DET(5,2)<1 THEN DET(5,2)=1:GOTO 2550 ' if number of dryers is
 less than
1 then set number of dryers to 1
2540 DET(5,2)=INT(DET(5,2))+1 'round to largest integer for number of
 dryers
2550 DET(5,3)=DET(4,1)*1.2/DET(5,2) ' Mg/day of concentrate & flux pe
r dryer
2600 IF DET(1,1)=1 THEN OPS=.8 ELSE IF DET(1,1)=2 THEN OPS=.8 ELSE IF
 DET(1,1)=3
 THEN OPS=.82 ' ratio of kg oxygen/kg copper
2610 DET(6,1)=(DIT(2,1)*OPS/DIT(19,1))*(1.01*DIT(23,1)/DIT(22,1)) ' M
g/day Oxyge
n Plant
2620 DET(6,1)=DET(6,1)/10+.5 ' prepare number for round off
2630 DET(6,1)=INT(DET(6,1))*10 ' round off number
2640 IF OP=1 AND AP=0 THEN 4100 ' if oxygen plant is costed and acid
plant is no
t, goto appropriate line number
2700 DET(7,1)=(DIT(2,1)*DIT(1,2)/(DIT(1,1)*DIT(19,1)))*((DIT(4,1)+DIT
(7,1))/DIT(
20,1))*98/32*.938:'Acid Plant Size
2710 DET(7,2)=.1644*DET(7,1)*DIT(4,1)/DIT(10,1):'nM3/min. flow of gas
es from pri
mary
2720 DET(7,3)=.1644*DET(7,1)*DIT(7,1)/DIT(11,1):'nM3/min. flow of gas
es from P-S
 converters
2730 DET(7,4)=(DET(7,2)*DIT(10,1)+DET(7,3)*DIT(11,1))/(DET(7,2)+DET(7
,3)):'Combi
ned SO2 percent by volume to acid plant
2740 DET(7,5)=DET(7,2)+DET(7,3):'Combined SO2 flow to acid plant
2745 DET(7,6)=INT(DET(7,1)*(1+DIT(24,1))/2300)+1:DET(7,7)=DET(7,1)*(1
+DIT(24,1))
/DET(7,6) ' if greater than 2300 make more plants
```

```
2750 IF EX=1 THEN 2800 ' if no existing plant, compute costs
2760 IF PT=1 THEN GOSUB 3500 ELSE GOSUB 3700 ' goto subroutine to tes
t for add-o
n
2770 GOTO 3200
2780 DET(7,6)=INT(DET(7,1)*(1+DIT(24,1))/2300)+1:DET(7,7)=DET(7,1)*(1
+DIT(24,1))
/DET(7,6) ' if greater than 2300 make more plants
2790 RETURN
2800 IF PT=1 THEN 3000 ' if single converter goto 3000
2810 IF DET(7,7)<=450 THEN 2900 ' if small acid plant goto 2900
2820 DET(8,1)=391*TA(1,YEAR)*DET(7,6)*(DET(7,7))^.624/(DET(7,4)^.555)
:' Acid pla
nt cost for DC/DA plant
2830 DET(8,2)=186*TA(1,YEAR)*(DET(7,1)^.6):' Storage rail & storage s
hipping for
 DC/DA plant
2840 DET(8,3)=DET(8,1)+DET(8,2):' total for DC/DA plant
2850 GOTO 3300
2900 DET(8,1)=801.2*TA(1,YEAR)*DET(7,6)*(DET(7,7))^.505/(DET(7,4)^.55
6):' Acid p
lant cost for DC/DA plant < 450
2910 DET(8,2)=186*TA(1,YEAR)*(DET(7,1)^.6):' Storage rail & storage s
hipping for
 DC/DA plant <450
2920 DET(8,3)=DET(8,1)+DET(8,2):' total for DC/DA plant < 450
2930 GOTO 3300
3000 IF DET(7,7)<=450 THEN 3100 ' if small acid plant goto 3100
3010 DET(8,1)=344.1*TA(1,YEAR)*DET(7,6)*(DET(7,7))^.624/(DET(7,4)^.55
5)*.998:' A
cid plant cost for SC/SA plant
3020 DET(8,2)=186*TA(1,YEAR)*(DET(7,1)^.6):' Storage rail & storage s
hipping for
 SC/SA plant
3030 DET(8,3)=DET(8,1)+DET(8,2):' total for SC/SA plant
3040 GOTO 3300
3100 DET(8,1)=705.1*TA(1,YEAR)*DET(7,6)*(DET(7,7))^.505/(DET(7,4)^.55
6)*.998:' A
cid plant cost for SC/SA plant < 450
3110 DET(8,2)=186*TA(1,YEAR)*(DET(7,1)^.6):' Storage rail & storage s
hipping for
 SC/SA plant <450
3120 DET(8,3)=DET(8,1)+DET(8,2):' total for SC/SA plant < 450
3130 GOTO 3300
3200 DET(12,1)=DET(7,1)*(1+DIT(24,1))*5:' acid facilities required fo
r add-on
3210 DET(8,2)=70.8*TA(1,YEAR)*1.15*(DET(12,1)^.6):' Storage rail & st
orage shipp
```

```
ing for existing plant <450
3220 DET(8,3)=DET(8,1)+DET(8,2)
3300 IF AP<>1 THEN 4100
3305 IF PT=1 THEN 3900
3310 COSTS(63,1)=1.102*(5.8675/DET(7,4)+57.75)*DET(7,1)*DIT(19,1)*TB(
1,1)
3315 COSTS(66,1)=204.44*DET(7,1)*DIT(19,1)*TB(1,2)/1000
3320 COSTS(67,1)=250*DET(7,1)*DIT(19,1)*TB(1,3)/1000
3325 COSTS(51,1)=.01256*DET(7,1)*DIT(19,1)*TB(2,1)
3330 COSTS(56,1)=12*2080*TB(3,1)
3335 COSTS(57,1)=COSTS(56,1)*TB(3,2)
3340 COSTS(58,1)=DET(8,1)*TB(4,1)
3345 COSTS(59,1)=COSTS(58,1)*TB(4,2)
3350 COSTS(60,1)=DET(8,1)*TB(4,3)
3355 COSTS(62,1)=(COSTS(56,1)+COSTS(57,1)+COSTS(58,1)+COSTS(59,1))*TB
(5,1)
3360 COSTS(61,1)=(COSTS(58,1)+COSTS(59,1)+COSTS(60,1))*TB(6,1)
3365 COSTS(71,1)=(COSTS(56,1)+COSTS(57,1)+COSTS(58,1)+COSTS(59,1)+COS
TS(60,1)+CO
STS(61,1))*TB(7,1)
3370 COSTS(76,1)=DET(8,1)*TB(8,1)
3375 COSTS(78,1)=DET(8,1)*TB(9,1)
3380 COSTS(79,1)=DET(8,1)*TB(11,1)
3385 FOR I%=51 TO 79:COSTS(80,1)=COSTS(80,1)+COSTS(I%,1):NEXT I%
3390 COSTS(80,1)=COSTS(80,1)+COSTS(78,2)
3400 COSTS(63,4)=(26280+.069*DET(7,1))*DIT(19,1)*TB(1,1)
3410 COSTS(67,4)=62.5*DET(7,1)*DIT(19,1)*TB(1,3)
3415 IF DET(7,1)<635 THEN COSTS(56,4)=1*2080*TB(3,1):GOTO 3425
3420 COSTS(56,4)=2*2080*TB(3,1)
3425 COSTS(57,4)=COSTS(56,4)*TB(3,2)
3430 COSTS(58,4)=.5*DET(8,2)*TB(4,1)
3435 COSTS(59,4)=COSTS(58,4)*TB(4,2)
3440 COSTS(60,4)=.5*DET(8,2)*TB(4,3)
3445 COSTS(62,4)=(COSTS(56,4)+COSTS(57,4)+COSTS(58,4)+COSTS(59,4))*TB
(5,1)
3450 COSTS(61,4)=(COSTS(58,4)+COSTS(59,4)+COSTS(60,4))*TB(6,4)
3455 COSTS(71,4)=(COSTS(56,4)+COSTS(57,4)+COSTS(58,4)+COSTS(59,4)+COS
TS(60,4)+CO
STS(61,4))*TB(7,1)
3460 COSTS(76,4)=DET(8,2)*TB(8,1)
3465 COSTS(78,4)=DET(8,2)*TB(9,1)
3470 COSTS(79,4)=DET(8,2)*TB(11,1)
3475 FOR I%=51 TO 79:COSTS(80,4)=COSTS(80,4)+COSTS(I%,4):NEXT I%
3480 COSTS(80,4)=COSTS(80,4)+COSTS(78,4)
3485 FOR I%=51 TO 80:IF I%=78 THEN COSTS(I%,2)=COSTS(I%,2)+COSTS(I%,4
) ELSE COST
S(I%,1)=COSTS(I%,1)+COSTS(I%,4)
3490 NEXT I%
```

```
3495 IF OP=0 THEN GOSUB 4300:GOSUB 30000:GOTO 40000 ELSE GOTO 4100
3500 IF DET(7,4)<=PS THEN DET(7,1)=DET(7,1)*(1+DIT(24,1))-PC
3510 GOSUB 2780
3520 IF DET(7,7)<450 THEN 3550
3530 DET(8,1)=391*TA(1,YEAR)*DET(7,6)*(DET(7,7)^.624)*1.15/(DET(7,5)^
.555)
3540 RETURN
3550 DET(8,1)=801.2*TA(1,YEAR)*DET(7,6)*(DET(7,7)^.505)*1.15/(DET(7,5
)^.556)
3560 RETURN
3595 GOTO 40000
3700 IF DET(7,4)<=PS THEN DET(7,1)=DET(7,1)*(1+DIT(24,1))-PC
3710 GOSUB 2780
3720 IF DET(7,7)<450 THEN 3750
3730 DET(8,1)=344.1*TA(1,YEAR)*DET(7,6)*(DET(7,7)^.624)*1.15/(DET(7,4
)^.555)*.99
8
3740 RETURN
3750 DET(8,1)=705.1*TA(1,YEAR)*DET(7,6)*(DET(7,7)^.505)*1.15/(DET(7,4
)^.556)*.99
8
3760 RETURN
3900 COSTS(63,1)=1.102*(4.1875/DET(7,4)+41.25)*DET(7,1)*DIT(19,1)*TB(
1,1)
3905 COSTS(66,1)=204.44*DET(7,1)*DIT(19,1)*TB(1,2)/1000
3910 COSTS(67,1)=250*DET(7,1)*DIT(19,1)*TB(1,3)/1000
3915 COSTS(51,1)=.01256*DET(7,1)*DIT(19,1)*TB(2,1)
3920 COSTS(56,1)=12*2080*TB(3,1)
3925 COSTS(57,1)=COSTS(56,1)*TB(3,2)
3930 COSTS(58,1)=DET(8,1)*TB(4,1)
3935 COSTS(59,1)=COSTS(58,1)*TB(4,2)
3940 COSTS(60,1)=DET(8,1)*TB(4,3)
3945 COSTS(62,1)=(COSTS(56,1)+COSTS(57,1)+COSTS(58,1)+COSTS(59,1))*TB
(5,1)
3950 COSTS(61,1)=(COSTS(58,1)+COSTS(59,1)+COSTS(60,1))*TB(6,1)
3955 COSTS(71,1)=(COSTS(56,1)+COSTS(57,1)+COSTS(58,1)+COSTS(59,1)+COS
TS(60,1)+CO
STS(61,1))*TB(7,1)
3960 COSTS(76,1)=DET(8,1)*TB(8,1)
3965 COSTS(78,1)=DET(8,1)*TB(9,1)
3970 COSTS(79,1)=DET(8,1)*TB(11,1)
3975 FOR I%=51 TO 79:COSTS(80,1)=COSTS(80,1)+COSTS(I%,1):NEXT I%
3980 COSTS(80,1)=COSTS(80,1)+COSTS(78,2)
3990 GOTO 3400
4100 DET(21,1)=195*TA(5,YEAR)*(DET(6,1)^.9)
4200 IF OP=0 THEN 4300
4205 COSTS(63,5)=396.8*DIT(2,1)*DIT(25,1)*TB(1,1)
4210 COSTS(67,5)=3477*DIT(2,1)*DIT(25,1)*TB(1,3)/1000
```

```
4215 COSTS(51,5)=.00485*DET(6,1)*DIT(10,1)*TB(2,5)
4220 COSTS(56,5)=8*2080*TB(3,1)
4225 COSTS(57,5)=COSTS(56,5)*TB(3,2)
4230 COSTS(58,5)=DET(21,1)*.01875
4235 COSTS(59,5)=DET(21,1)*.00375
4240 COSTS(60,5)=DET(21,1)*.02
4245 COSTS(62,5)=(COSTS(56,5)+COSTS(57,5)+COSTS(58,5)+COSTS(59,5))*TB
(5,1)
4250 COSTS(61,5)=(COSTS(58,5)+COSTS(59,5)+COSTS(60,5))*TB(6,1)
4255 COSTS(71,5)=(COSTS(56,5)+COSTS(57,5)+COSTS(58,5)+COSTS(59,5)+COS
TS(60,5)+CO
STS(61,5))*TB(7,1)
4260 COSTS(76,5)=DET(21,1)*TB(8,1)
4265 COSTS(78,5)=DET(21,1)*TB(9,1)
4270 COSTS(79,5)=DET(21,1)*TB(11,1)
4275 FOR I%=51 TO 79:COSTS(80,5)=COSTS(80,5)+COSTS(I%,5):NEXT I%
4280 FOR I%=51 TO 80:IF I%=78 THEN COSTS(I%,2)=COSTS(I%,5):I%=I%+1 EL
SE COSTS(I%
,1)=COSTS(I%,1)+COSTS(I%,5)
4285 NEXT I%
4290 GOSUB 4300:GOSUB 30000:GOTO 40000
4300 REM >> Output Subroutine for user-defined parameters <<
4302 PRINT #1,CHR$(34);DATE$;CHR$(34)
4305 IF DET(1,1)=1 THEN FT$="INCO" ELSE IF DET(1,1)=2 THEN FT$="Oxyge
n Sprinkle"
 ELSE FT$="Oxy-Fuel"
4310 PRINT #1,CHR$(34);FT$;CHR$(34)
4312 PRINT #1,DIT(2,1)
4313 PRINT #1,DET(4,1)
4315 PRINT #1,DET(7,1)
4320 PRINT #1,
4325 PRINT #1,DIT(1,1)
4330 PRINT #1,DIT(1,2)
4335 PRINT #1,DIT(1,3)
4340 PRINT #1,DIT(10,1)
4345 IF DIT(26,1)=1 THEN PRINT #1,CHR$(34);"Easy";CHR$(34) ELSE IF DI
T(26,1)=2 T
HEN PRINT #1,CHR$(34);"Moderate";CHR$(34) ELSE PRINT CHR$(34);"Diffic
ult";CHR$(3
4)
4350 PRINT #1,RET
4355 PRINT #1,DIT(27,1)
4360 PRINT #1,
4390 IF AP=1 OR OP=1 THEN RETURN
4400 DET(24,1)=DET(4,2)*RET*(1506.2*TA(6,YEAR)+204.4*TA(7,YEAR))
4500 DET(25,1)=.25*DET(24,1)*RET
4600 IF DET(1,1)=3 THEN 4650
4610 DET(26,1)=50.94*(DET(5,3)^.6)*DET(5,2)*TA(3,YEAR)*RET
```

```
4620 GOTO 4700
4650 DET(26,1)=51.88*(DET(5,3)^.6)*DET(5,2)*TA(3,YEAR)*RET
4660 GOTO 4750
4700 DET(27,1)=(25.7*(DET(5,3)^.3)+.0202*(DET(5,3)^.975))*TA(5,YEAR)*
DET(5,2)
4710 GOTO 4800
4750 DET(27,1)=(25.94*(DET(5,3)^.3)+.0208*(DET(5,3)^.975))*TA(5,YEAR)
*DET(5,2)
4760 GOTO 4850
4800 DET(28,1)=13.11*(DET(5,3)^.65)*TA(3,YEAR)*DET(5,2)*RET
4810 GOTO 4900
4850 DET(28,1)=13.38*(DET(5,3)^.65)*TA(3,YEAR)*DET(5,2)*RET
4860 GOTO 4950
4900 DET(29,1)=.734*(DET(5,3)^.5)*TA(2,YEAR)*DET(5,2)*RET
4910 GOTO 5000
4950 DET(29,1)=.745*(DET(5,3)^.5)*TA(2,YEAR)*DET(5,2)*RET
4960 GOTO 5050
5000 DET(30,1)=.907*(DET(5,3)^.61)*TA(4,YEAR)*DET(5,2)*RET
5010 GOTO 5100
5050 DET(30,1)=.925*(DET(5,3)^.61)*TA(4,YEAR)*DET(5,2)*RET
5060 GOTO 5160
5100 IF DET(1,1)=2 THEN GOTO 5140
5110 DET(31,1)=27.2*(DET(4,3)^.65)*DET(4,2)*TA(7,YEAR)*RET
5120 GOTO 5200
5140 DET(31,1)=28.2*(DET(4,3)^.65)*DET(4,2)*TA(7,YEAR)*RET
5150 GOTO 5240
5160 DET(31,1)=27.03*(DET(4,3)^.65)*DET(4,2)*TA(7,YEAR)*RET
5170 GOTO 5270
5200 DET(32,1)=15.62*(DET(4,3)^.6)*DET(4,2)*TA(3,YEAR)*RET
5210 GOTO 5300
5240 DET(32,1)=16.52*(DET(4,3)^.6)*DET(4,2)*TA(3,YEAR)*RET
5250 GOTO 6000
5270 DET(32,1)=10.88*(DET(4,3)^.6)*DET(4,2)*TA(3,YEAR)*RET
5280 GOTO 6300
5300 DET(33,1)=DIT(2,1)*DIT(1,2)*DIT(4,1)*2/(DIT(1,1)*DIT(20,1)*DIT(1
9,1))
5310 DET(33,2)=.243*DET(33,1)/DIT(10,1)
5320 DET(33,3)=(273+1260)/273*DET(33,2)
5330 DET(33,4)=DET(33,3)/DET(4,1)
5340 DET(33,5)=3.1*((DET(33,4)*DET(4,3))^.5)*TA(1,YEAR)*DET(4,2)
5350 DET(33,6)=168.6*(.0329*(DET(33,4)*DET(4,3))^.5+.3048)*TA(2,YEAR)
*DET(4,2)
5400 DET(34,1)=1.996*(DET(4,3)^.776)*TA(3,YEAR)*DET(4,2)
5500 DET(35,1)=1.2236*(DET(4,3)^.61)*TA(2,YEAR)*DET(4,2)
5600 DET(36,1)=1.816*(DET(33,4)*DET(4,3))^.5*TA(3,YEAR)*DET(4,2)
5700 DET(37,1)=.8188*DET(33,3)
5710 DET(37,2)=.1284*DET(33,1)*TA(3,YEAR)
5800 DET(38,1)=1.7487*DET(33,2)
```

```
5810 DET(38,2)=30.49*DET(38,1)^.6*TA(3,YEAR)
5900 DET(39,1)=1.2403*DET(33,2)
5910 DET(39,2)=.634*DET(39,1)^.6*TA(5,YEAR)
5920 GOTO 6600
6000 DET(40,1)=7.642*DET(4,3)^.65*TA(7,YEAR)*DET(4,2)*RET
6100 DET(41,1)=DIT(2,1)*DIT(1,2)*DIT(4,1)*2/(DIT(1,1)*DIT(20,1)*DIT(1
9,1))
6110 DET(41,2)=.243*DET(41,1)/DIT(10,1)
6120 DET(41,3)=2.2575*DET(41,2)
6130 DET(41,4)=DET(41,3)/DET(4,1)
6140 DET(41,5)=3.875*(DET(41,4)*DET(4,3))^.5*TA(1,YEAR)*DET(4,2)
6150 DET(41,6)=168.6*(.0329*(DET(41,4)*DET(4,3))^.5+.3048)*TA(2,YEAR)
*DET(4,2)
6200 DET(42,1)=1.7487*DET(41,2)
6210 DET(42,2)=30.49*DET(42,1)^.6*TA(3,YEAR)
6220 GOTO 6600
6300 DET(43,1)=4.78*DET(4,3)^.65*TA(7,YEAR)*DET(4,2)
6400 DET(44,1)=DIT(2,1)*DIT(1,2)*DIT(4,1)*2/(DIT(1,1)*DIT(20,1)*DIT(1
9,1))
6410 DET(44,2)=.243*DET(44,1)/DIT(10,1)
6420 DET(44,3)=2.156*DET(44,2)
6430 DET(44,4)=DET(44,3)/DET(4,1)
6440 DET(44,5)=4.9*(DET(44,4)*DET(4,3))^.5*TA(1,YEAR)*DET(4,2)
6450 DET(44,6)=168.6*(.03*(DET(44,4)*DET(4,3))^.5+.3048)*TA(2,YEAR)*D
ET(4,2)
6500 DET(45,1)=1.7487*DET(44,2)
6510 DET(45,2)=30.49*DET(45,1)^.6*TA(3,YEAR)
6600 GOSUB 30000
6700 GOSUB 50000
6800 GOSUB 40000
10000 '
10010 ' Numeric input subroutine
10020 '
10030 K$="":S$="":C%=0:WHILE C%<MC% ' loop on input characters
10040 LOCATE Y%,X%+C%,1:PRINT " ";:LOCATE ,X%+C%
10045 K$=INKEY$:IF K$="" THEN 10045 ' Position cursor, wait for key p
ress
10050 IF K$=CHR$(13) THEN 10100 ' if <cr> then end
10055 IF K$= CHR$(27) THEN C%=-1:GOTO 10100 ' If <esc> set counter ne
gative and
return
10060 IF K$= CHR$(8) AND C%<> 0 THEN C%=C%-1:S$=LEFT$(S$,C%):GOTO 100
90 ' Backsp
ace; delete one character from string
10070 IF K$="-" OR K$>="0" AND K$<="9" OR K$="." THEN C%=C%+1:S$=S$+K
$ ELSE K$="
" ' only numerics accepted
10075 IF C%=1 THEN PRINT STRING$(MC%," "):LOCATE Y%,X%
```

```
10080 PRINT USING "!";K$; ' Echo character if valid
10090 WEND
10100 RETURN
20000 '
20010 ' Disk Exception Routine
20020 '
20030 LOCATE 24,1,0
20040  IF ERR=53 THEN PRINT "That file does not exist; do you want to
 create it
(y/n)?";:K$=INPUT$(1):IF K$="n" THEN RESUME 645 ELSE IF K$= "y" THEN
RESUME 700
20050 COLOR 18:PRINT " Disk Error " ERR;:COLOR 7
20060 IF ERR=64 OR ERR=52 THEN PRINT ": improper file name";
20070 BEEP:FOR I%= 1 TO 3000:NEXT : IF ERL= 670 OR ERL=680 THEN RESUM
E 645 ELSE
IF
20080 STOP
30000 FOR I%=26 TO 45
30005 J%=1
30010 IF I%=33 OR I%=41 OR I%=44 THEN J%=5
30020 IF I%>36 AND I%<40 THEN J%=2
30023 IF I%=42 THEN J%=2
30026 IF I%=45 THEN J%=2
30030 COSTS(1,1)=COSTS(1,1)+DET(I%,J%)
30040 NEXT I%
30050 COSTS(1,1)=COSTS(1,1)+DET(33,6)
30053 COSTS(1,1)=COSTS(1,1)+DET(41,6)
30056 COSTS(1,1)=COSTS(1,1)+DET(44,6)
30060 COSTS(2,1)=(.456+(DET(1,1)-1)/1000)*COSTS(1,1)
30070 COSTS(3,1)=.084*(COSTS(1,1)+COSTS(2,1))
30080 COSTS(4,1)=(.081+INT(DET(1,1)/3)/1000)*(COSTS(1,1)+COSTS(2,1))
30090 COSTS(5,1)=(.048+(DET(1,1)-1)/1000)*(COSTS(1,1)+COSTS(2,1))
30100 COSTS(6,1)=DET(25,1)
30110 COSTS(7,1)=DET(24,1)
30120 COSTS(8,1)=DET(21,1)
30130 COSTS(9,1)=DET(8,3)
30140 COSTS(10,1)=8.999999E-03*(COSTS(8,1)+COSTS(9,1))
30150 FOR I%=1 TO 10:COSTS(11,1)=COSTS(11,1)+COSTS(I%,1):NEXT I%
30160 FOR I%=1 TO 7:SUB=SUB+COSTS(I%,1):NEXT I%:SUB=SUB+COSTS(10,1)
30170 COSTS(12,1)=.1*SUB
30180 COSTS(13,1)=.035*SUB
30190 COSTS(22,1)=.05*(SUB+COSTS(13,1))
30200 COSTS(23,1)=.25*(SUB+COSTS(12,1)+COSTS(13,1)+COSTS(22,1))
30210 FOR I%=11 TO 23:COSTS(24,1)=COSTS(24,1)+.105*COSTS(I%,1):NEXT I
%
30220 FOR I%=12 TO 24:COSTS(30,1)=COSTS(30,1)+COSTS(I%,1):NEXT I%
30230 COSTS(31,1)=COSTS(11,1)+COSTS(30,1)
30240 REM the rest of the 30000 block reserved for output
```

```
30250 REM >> Output of Capital Costs <<
30260 DATA 14,22,25,30
30270 FOR I%=1 TO 4:READ NOBREAK(I%)
30280 NEXT I%
30285 PRINT #1,
30290 FOR I%=1 TO 31
30300 FOR J%=1 TO 3 STEP 2:IF I%=NOBREAK(J%) THEN I%=NOBREAK(J%+1) EL
SE NEXT J%
30303 IF I%=11 OR I%=12 OR I%=31 THEN PRINT #1,
30305 IF I%=12 THEN PRINT #1,
30310 PRINT #1,COSTS(I%,1)
30320 NEXT I%
30330 RETURN
40000 REM >> Output of Annual Operating Costs <<
40010 DATA 52,56,68,71,72,76,77,78,81,82,84,90,93,100
40020 FOR I%=1 TO 14:READ NOBREAK(I%):NEXT I%
40025 PRINT #1,:PRINT #1,:PRINT #1,
40030 FOR I%=51 TO 102
40040 FOR J%=1 TO 13 STEP 2:IF I%=NOBREAK(J%) THEN I%=NOBREAK(J%+1)
40050 NEXT J%
40055 IF I%>79 THEN PRINT #1,
40057 IF I%=100 THEN PRINT #1,
40060 PRINT #1,COSTS(I%,1)
40070 IF I%=78 THEN FOR J%=2 TO 3:PRINT #1, COSTS(I%,J%): NEXT J%
40080 NEXT I%
40150 CLOSE
40160 OPEN "o",1,INFILE$+".dbg"
40170 FOR I%=1 TO 45
40180 PRINT #1,I%;
40190 FOR J%=1 TO 10
40200 PRINT #1, "  ";DET(I%,J%);
40210 NEXT J%
40220 PRINT #1,
40230 NEXT I%
40240 CLOSE #1
41000 CLS
41005 LOCATE 10:PRINT "Do another (Y/N)":Y$=INPUT$(1):IF Y$="Y" OR Y$
="y" THEN R
UN
41010 IF Y$="N" OR Y$="n" THEN SYSTEM
41020 GOTO 41005
50000 COSTS(51,1)=.03*DET(7,1)*TB(2,1)*DIT(19,1)
50010 IF DET(1,1)>1 THEN 50040
50020 IF DIT(2,1)=<181400! THEN COSTS(56,1)=(131-(181400!-DIT(2,1))/7
560)*2080*T
B(3,1):GOTO 50090
50030 COSTS(56,1)=(131+(DIT(2,1)-181400!)/2297)*2080*TB(3,1):GOTO 500
90
```

```
50040 IF DET(1,1)>2 THEN 50070
50050 IF DIT(2,1)<=181400! THEN COSTS(56,1)=(151-(181400!-DIT(2,1))/5
335)*2080*T
B(3,1):GOTO 50090
50060 COSTS(56,1)=(151+(DIT(2,1)-181400!)/1960)*2080*TB(3,1):GOTO 500
90
50070 IF DIT(2,1)<=181400! THEN COSTS(56,1)=(151-(181400!-DIT(2,1))/5
335)*2080*T
B(3,1):GOTO 50090
50080 COSTS(56,1)=(151+(DIT(2,1)-181400!)/1517)*2080*TB(3,1)
50090 COSTS(57,1)=TB(3,2)*COSTS(56,1)
50100 COSTS(58,1)=TB(4,1)*COSTS(31,1)
50110 COSTS(59,1)=COSTS(58,1)*TB(4,2)
50120 COSTS(60,1)=COSTS(31,1)*TB(4,3)
50130 COSTS(61,1)=TB(6,1)*(COSTS(58,1)+COSTS(59,1)+COSTS(60,1))
50140 COSTS(62,1)=TB(5,1)*(COSTS(56,1)+COSTS(57,1)+COSTS(58,1)+COSTS(
59,1))
50142 IF EX=1 AND PT=1 THEN COSTS(63,2)=1.102*(1.68/DET(7,4)+16.5)*DE
T(7,1)*DIT(
19,1)*TB(1,1)
50144 IF EX=2 AND PT=1 THEN COSTS(63,2)=1.102*(4.1875/DET(7,4)+41.25)
*PC*DIT(19,
1)*TB(1,1)
50146 IF EX=2 AND PT=2 THEN COSTS(63,2)=1.102*(5.8675/DET(7,4)+57.75)
*PC*DIT(19,
1)*TB(1,1)
50150 IF DET(1,1)=1 THEN COSTS(63,1)=232.06*DET(4,1)*DIT(19,1)*TB(1,1
)
50160 IF DET(1,1)=2 THEN COSTS(63,1)=240*DET(4,1)*DIT(19,1)*TB(1,1)
50170 IF DET(1,1)=3 THEN COSTS(63,1)=162.95*DET(4,1)*DIT(19,1)*TB(1,1
)
50175 COSTS(63,1)=COSTS(63,1)-COSTS(63,2)
50180 IF DET(1,1)<3 THEN COSTS(64,1)=7.861*DET(4,1)*DIT(19,1)*TB(2,3)
50190 IF DET(1,1)=3 THEN COSTS(64,1)=47.94*DET(4,1)*DIT(19,1)*TB(2,3)
50200 IF DET(1,1)=2 THEN COSTS(64,1)=COSTS(64,1)+.029*DET(4,1)*DIT(19
,1)*TB(2,2)

50210 IF DET(1,1)<3 THEN COSTS(65,1)=.852*DET(4,1)*DIT(19,1)*TB(2,4)
50220 IF DET(1,1)=3 THEN COSTS(65,1)=1.278*DET(4,1)*DIT(19,1)*TB(2,4)
50230 IF DET(1,1)=1 THEN COSTS(66,1)=.704*DET(4,1)*DIT(19,1)*TB(1,2)
50240 IF DET(1,1)=2 THEN COSTS(66,1)=.643*DET(4,1)*DIT(19,1)*TB(1,2)
50250 IF DET(1,1)=3 THEN COSTS(66,1)=.683*DET(4,1)*DIT(19,1)*TB(1,2)
50260 IF DET(1,1)=1 THEN COSTS(67,1)=.297*DET(4,1)*DIT(19,1)*TB(1,3)
50270 IF DET(1,1)=2 THEN COSTS(67,1)=.315*DET(4,1)*DIT(19,1)*TB(1,3)
50280 IF DET(1,1)=3 THEN COSTS(67,1)=.288*DET(4,1)*DIT(19,1)*TB(1,3)
50290 COSTS(71,1)=(COSTS(56,1)+COSTS(57,1)+COSTS(58,1)+COSTS(59,1)+CO
STS(60,1)+C
OSTS(61,1))*TB(7,1)
```

```
50300 COSTS(76,1)=COSTS(31,1)*TB(8,1)
50310 COSTS(78,1)=1.105*DET(8,3)*TB(9,2)
50320 COSTS(78,2)=1.105*DET(21,1)*TB(9,1)
50330 COSTS(78,3)=(COSTS(31,1)-(1.105*(COSTS(8,1)+COSTS(9,1))))*TB(9,
3)
50340 COSTS(79,1)=COSTS(31,1)*TB(11,1)
50350 FOR I%=51 TO 79:IF I%=78 THEN FOR J%=2 TO 3:COSTS(80,1)=COSTS(8
0,1)+COSTS(
I%,J%):NEXT J%
50355 COSTS(80,1)=COSTS(80,1)+COSTS(I%,1):NEXT I%
50360 COSTS(82,1)=.965*DET(7,1)*TB(12,2)*DIT(19,1)
50370 IF DET(1,1)=2 THEN COSTS(83,1)=34.86*DET(4,1)*DIT(19,1)*TB(12,1
)
50380 IF DET(1,1)=3 THEN COSTS(83,1)=63.17*DET(4,1)*DIT(19,1)*TB(12,1
)
50390 COSTS(90,1)=COSTS(80,1)-COSTS(82,1)
50400 COSTS(91,1)=COSTS(80,1)-COSTS(83,1)
50410 COSTS(92,1)=COSTS(90,1)-COSTS(83,1)
50420 COSTS(100,1)=COSTS(92,1)/(DIT(2,1)*1000)
50430 COSTS(101,1)=COSTS(91,1)/(DIT(2,1)*1000)
50440 COSTS(102,1)=COSTS(101,1)+.00183*TB(2,1)
50450 COSTS(82,1)=-1*COSTS(82,1):COSTS(83,1)=-1*COSTS(83,1)
50460 RETURN
```

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APPENDIX B

GUIDE TO THE EPA COST ESTIMATION MODEL FOR SMELTER SCRUBBER COSTS

INTRODUCTION

This appendix describes the proper procedures for accessing and using a computerized model approach to estimating the capital and annual operating costs of selected scrubbing processes applied to nonferrous metal smelters to reduce sulfur dioxide emissions. The program is accessible through EPA's UNIVAC 1100 computer in Research Triangle Park, North Carolina. Access may be gained through the user's password and the file name @XQT SMT*SMELTER.MAIN.

The model estimates costs for four flue gas scrubbing (FGS) processes: lime, limestone, magnesium oxide, and citrate. Various options are provided for the ultimate disposition of the sulfur-bearing product of the FGS model process systems. For the lime and limestone systems, scrubber output options consist of the production of gypsum or sludge; for the magnesium oxide and citrate systems, the output is a concentrated sulfur dioxide stream that is suitable for treatment in a liquid sulfur dioxide plant. The concentrated sulfur dioxide stream also could be mixed with dilute sulfur dioxide streams from other smelter processes, and the resulting stream could be processed in a sulfuric acid plant. The final strength of the stream to the acid plant at each smelter would depend on the sulfur dioxide content and total volume, which would then determine the acid plant costs. Because of variation in the sulfur dioxide content of the combined gases, no acid plant costs are included.

The user can program input variables that will allow estimates of fairly site-specific costs. Cost indices are provided for each equipment process category so they can be adjusted for any year between 1970 and 1981 or projected beyond 1981.

DESCRIPTION OF MODEL

Several factors enter into the selection of a control system for a specific site; these include the required efficiency of sulfur dioxide (SO_2) and/or particulate removal, site layout (e.g., space for disposal ponds), availability of raw materials, energy requirements, disposal of the collected product (as gypsum, liquid SO_2, or sludge), and suitability for use with the existing (retrofit) or selected (new smelter) process equipment.

This computerized procedure can be used to estimate costs of four scrubbing systems: lime, limestone, magnesium oxide, and citrate. It will provide estimates of the capital and annual operating costs incurred by the scrubbing of nonferrous smelter discharge gases containing up to 3.5 percent SO_2. The user may select a variety of input and output parameters to suit specific site conditions and to develop more realistic costs. The user can specify the product formed (gypsum or sludge for lime or limestone; liquid SO_2, if desired, for MgO or citrate) and select input variables (flow, temperature, moisture, SO_2 concentration). Additional equipment items, such as stack, venturi, precooler, reheat system, or bypass system, can also be specified. The model will accommodate off-gases with SO_{22} concentrations from 0.5 to 3.5 percent by volume and flow rates of 84,950 to 679,600 Nm^3/h (50,000 to 400,000 scfm). The program may be used in a batch mode (with punched cards) or in an interactive mode (with a computer terminal).

Flow diagrams and schematic layouts were developed for nonregenerative (lime and limestone) and regenerative (magnesium oxide and citrate) systems. Options for handling the smelter off-gases prior to scrubbing included the following: precooler for gases with a temperature greater than 204°C followed by scrubbing; precooler with a venturi for particulate control for temperatures greater than 204°C and then scrubbing; venturi for particulate control without precooler if the incoming gas smelter stream was less than 204°C and then scrubbing; or direct to scrubbing when a gas temperature is below 204°C and particulate control is not required.

Schematic layouts were made for lime and limestone slurry makeup and storage systems; MgO makeup, storage, and recovery systems; citrate removal and regeneration system. Options for handling nonregenerative bleed streams from the scrubbers include the following: routing directly to a disposal pond; routing to a thickener and then to a disposal pond; routing to a thickener followed by vacuum filters or centrifuge and then to a disposal pond; and oxidation followed by centrifuge or vacuum filters to form gypsum for sale or storage. Schematic layouts were also made for liquid SO_2 for the regenerative models: MgO (compressor technique) and citrate (refrigeration technique).

The main drawback of a nonregenerative scrubbing system is that it requires space for disposal ponds adjacent to the existing smelter. The main drawbacks of a regenerative system are space requirements, finding a market for the SO_2 generated, and the additional energy required for the scrubbing systems and SO_2 recovery systems.

Determining the type of scrubbing system that would be most beneficial to the smelter involves a study of the following:

- Water availability
- Fuel costs
- Space availability
- Temperature of off-gases
- Particulate removal
- Required efficiency of the scrubbing system for SO_2 removal
- Flow limits of approximately 65,000 to 700,000 nm^3/h
- Electrical energy requirements versus existing electrical energy available
- Soil conditions
- Sludge disposal (ponding or selling)
- Market for liquid SO_2

The following equipment cost data were developed for each flow diagram and schematic:

- Material and estimated fabrication costs.

- Vendor-estimated costs (due to lack of total finite detailed information) or calculated costs.

- Estimated percentage factors were used for installation (moderate to difficult), piping, insulation, electrical, switch gear, instrumentation, foundations, painting, miscellaneous items (structural, stairs, piling, mobile equipment, spare parts, etc.), engineering, startup, contractor's fee and offsite expenses, contingency, and interest during construction (based on interest rate).

- Basic assumptions included the following:

    - Off-gas SO_2 removal efficiency of 85 percent for a limestone system, 90 percent for a lime system, 92 percent for an MgO system, and 95 percent for a citrate system

    - Installation factors of 1.0 for moderate, 1.16 for moderately difficult, and 1.3 for difficult

    - Taxes and insurance, 2.3 percent (if unknown)

    - Contingency, 15 to 25 percent (if unknown)

    - Years to construct, 2.5 (if unknown)

    - Depreciation, 12.5 years (if unknown)

    - Cost of capital, 10 percent (if unknown)

- Other adjustment factors
    - Size: Published literature [Guthrie, Klumpar, McGlammery, and PEI (calculated costs)]
    - Year: Chemical Engineering Plant Cost Index (the most appropriate subdivision).
    - Indirect costs: include engineering, contractor's fee and expenses, freight, offsite expenses, taxes, allowance for startup, and spares. The factor was based on an average of the calculated installed capital costs for a wide range of flows, SO_2 content, and types of scrubbing for all four scrubbing systems. These costs also included interest during construction and 15 percent contingency. The overall indirect costs are approximately 62 percent over the installed equipment costs.

Operating cost data were generated by summing total electrical usage for pumps, slurry and raw material handling, lighting, etc., based on design and utilization. The costs of fuel and raw materials were calculated from design data. The basic raw materials for scrubbing included stoichiometric ratios of 1.05 for citrate, 1.1 for lime and MgO, and 1.4 for limestone. Maintenance labor, supervision, and materials were selected as a percentage of the total capital cost. The percentages were based on past experience in other industries, on general discussions with electrical utility personnel, and on PEI in-house data.

Some of the design parameters used in developing the preliminary design and costs are shown in Table B-1.

TABLE B-1. COMPARISON OF KEY SYSTEM PARAMETERS

	Scrubbing reagent			
	Lime	Limestone	MgO	Citrate
Velocity through absorber, ft/s	10	10	10	6
Type of absorber	Spray tower with diffuser tray			Packed tower
Liquid-to-gas ratio, gal/1000 acfm	30	60	30	22.4
Stoichiometric ratio	1.1	1.4	1.1	1.0
Sludge, lb/lb SO_2				
Gypsum	2.61	3.33	-	-
Pond	3.48	4.44	-	-
Efficiency of SO_2 removal, %	90	85	92	95

Figure B-1 shows the results produced by this computerized cost estimating procedure for a 1 percent SO_2 gas stream for each of the four control systems. These data show that the capital costs range from about \$100 to \$300 per scfm of exhaust gas. Annual operating costs, including capital charges ranging from about \$50 to \$100 per scfm, are given in Figure B-2.

Chemical Engineering Cost Indexes from 1970 to 1981 permit the user to determine capital costs for any specific year back to 1970. Costs can also be projected forward for 2 or 3 years. Annual operating costs from 1970 also can be determined by insertion of capital costs and the costs of raw materials, power, water, labor, insurance, and taxes that existed during the specific year. Capital costs for 1970 through 1981 can be determined from the index costs or by use of plant-specific values.

COST EVALUATION

Basis for Capital Cost Information

Capital costs (see Table B-2) consist of direct equipment costs, installation and construction costs, ponding, and indirect costs (including construction, engineering, overhead, contractor's fee, interest during construction, and contingency). The capital costs are calculated in July 1981 dollars but can be escalated, as previously discussed.

Direct Costs--

Direct costs cover the purchased equipment installed on the site and materials, piping, instrumentation, electrical work, foundations, structural work, site work, insulation, painting, piling, and labor. Installed costs were determined by multiplying the equipment by selected installation factors.

The installed field costs are segregated into major specific areas, and the major items in each area were analyzed so the most appropriate Chemical Engineering Cost Indexes could be selected. The indexes for each item were weighed, and an index for that major area was determined. The following are the major areas and the corresponding Chemical Engineering Cost Indexes:

Major area	Cost index
Material handling	Process machinery
Feed preparation	Fabricated equipment
Precooler	Equipment, machinery, and supports
Venturi	Fabricated equipment
SO_2 scrubbing	Fabricated equipment

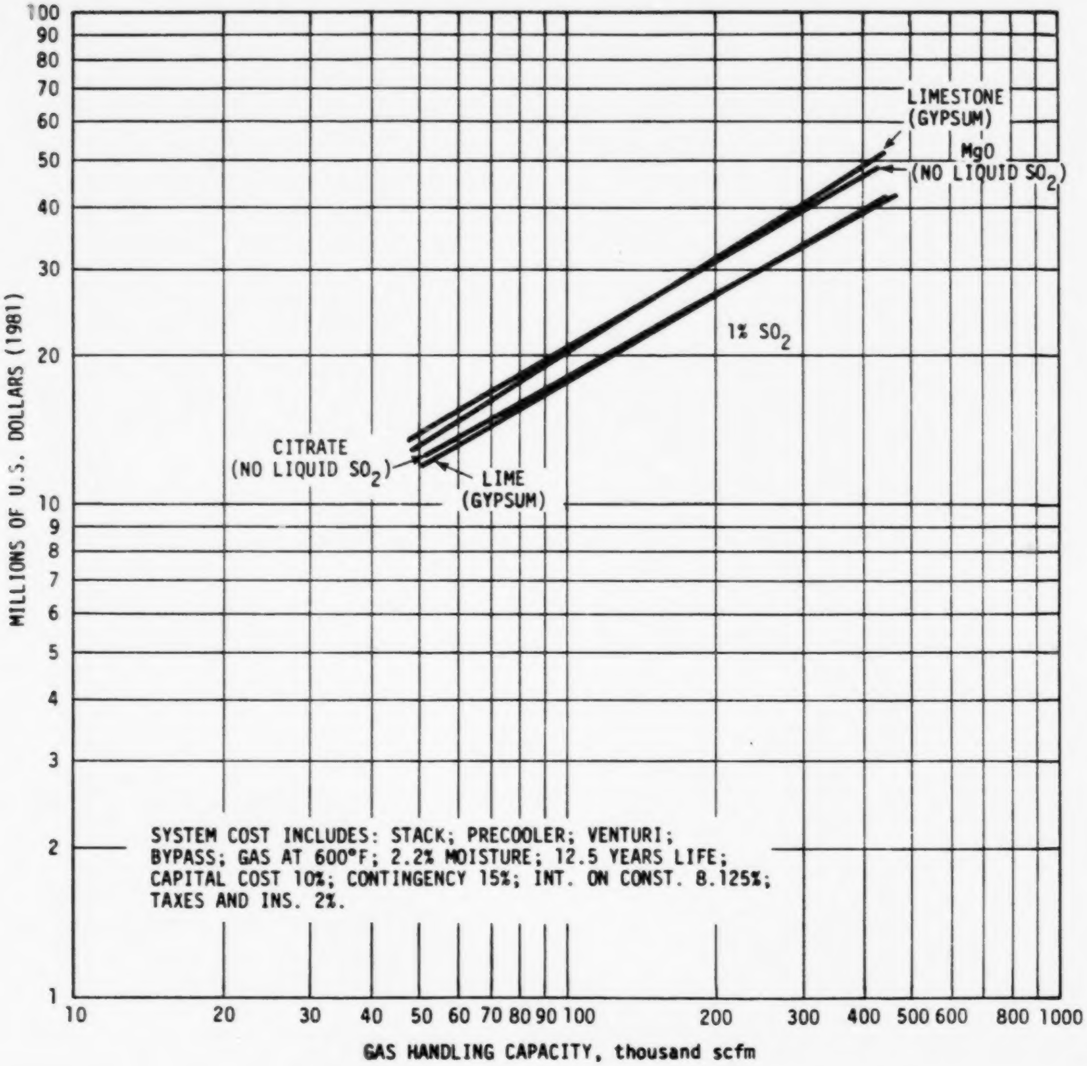

Figure B-1. Computer-estimated capital costs for four control systems in July 1981 dollars.

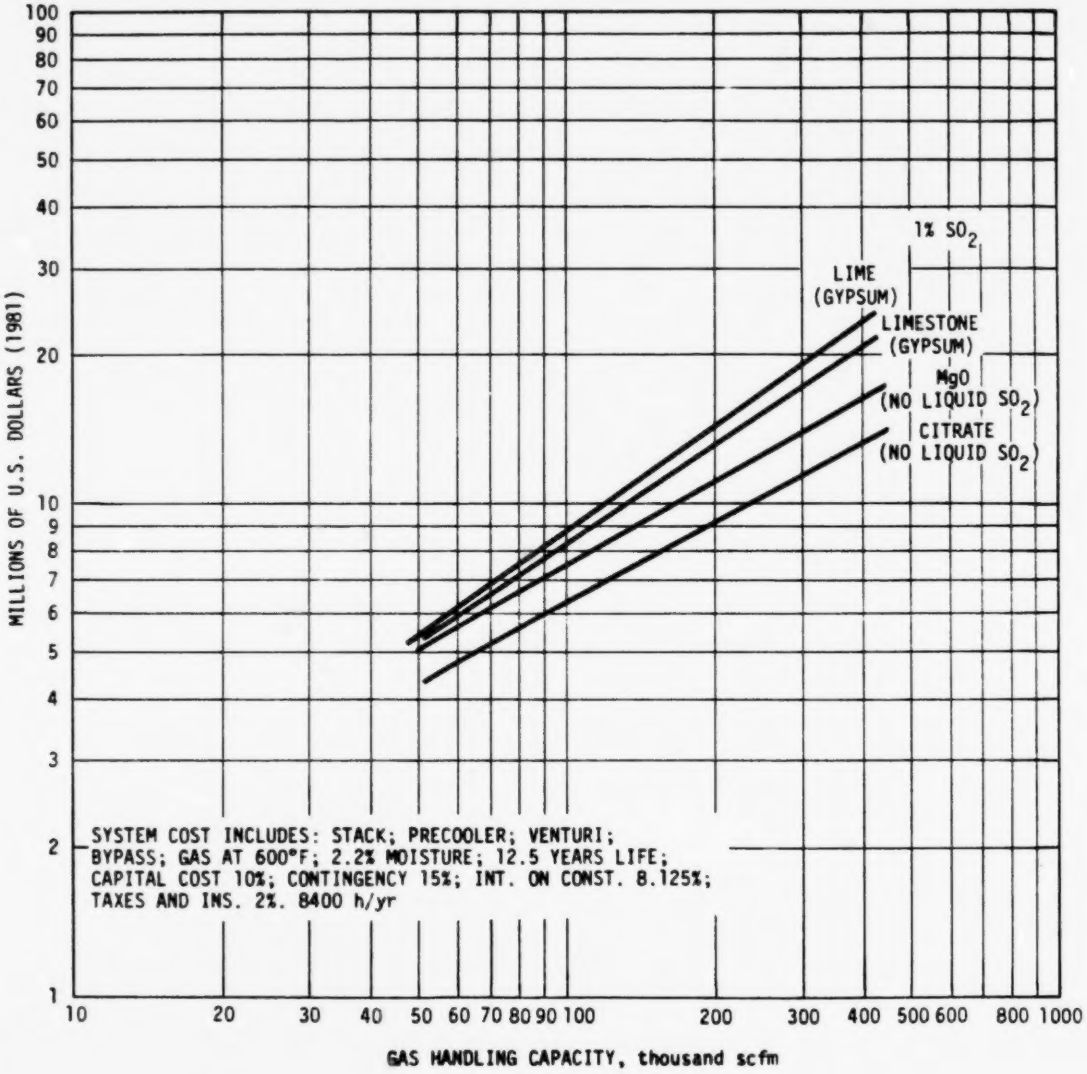

Figure B-2. Computer-estimated annual operating costs for four control systems.

TABLE B-2. FORMAT FOR TOTAL CAPITAL INVESTMENT

Direct costs:

- Base equipment and installed cost
- Subtotal of all base equipment and installed costs
- Ponding costs (disposal, cooling, emergency)
- Total of direct costs

Indirect costs:

- Engineering, administration, and overhead
- Contractor's fee
- Field costs (supervision, inspection, startup, offsites, freight, taxes, and spares)
- Interest during construction (based on total of direct costs plus indirect costs of engineering)
- Contingency (based on total of direct costs plus indirect costs of engineering, administration, overhead, contractor's fee, field costs, and interest during construction)

Total capital costs:

- Direct costs
- Indirect costs

If a cooling pond liner is required, add the cost to the total capital costs.

Major area (continued)	Cost index (continued)
Reheat and stack	Fabricated equipment
Solids disposal	Process machinery
MgO regeneration	Process machinery
Liquid SO_2	Pumps and compressors
Citrate regeneration	Fabricated equipment
Purge stream regeneration	Fabricated equipment
Emergency pond	Construction labor
Cooling pond	Construction labor
Disposal pond	Construction labor
Cooling pond liner	Chemical Engineering Plant Index

Indirect Costs--

Indirect costs cover three major areas: 1) costs for engineering, field, and overhead; 2) interest on capital during construction; and 3) contingency.

The major indirect costs (31.25% of total directs) cover engineering, administration, and overhead (10 percent); contractor's fee (7.5 percent); and field costs such as field supervision, inspection, startup, offsites, freight, taxes, and spares (13.75 percent).

Interest during construction is based on cost of capital times 0.325 times the years to install. Based on a period of 2-1/2 years and 10 percent capital costs, interest during construction would be 8.125 percent for the total project. This is based on the total of direct costs plus indirect costs. It is assumed that payout for construction and equipment is low in the beginning and increases near the last half of the project and that the money borrowed earns interest until required for payoff of the equipment or construction costs.

Contingency is estimated to be 15 percent of the total of direct costs plus indirect costs. Depending on the FGS system and the supplier, this could vary from 10 to 20 percent.

No costs were allowed for pilot plants (if required), development work, land, new site development, office buildings, laboratories, shops, etc.

Basis For Operating Cost Estimation

The user can input directly the operating costs for raw materials, utilities, labor, maintenance, overhead, and the fixed costs of depreciation (straight-line), insurance, taxes, and the cost of capital. If these values are unknown, the programmed values can be used.

Quantities of raw materials and utilities are based on the material balances for the FGS system used for SO_2 removal. Operating labor requirements per shift were estimated to be five persons per shift for the lime and limestone systems, eight persons per shift for the MgO system, and six persons per shift for the citrate system. Supervision for operating labor is estimated to be 15 percent of the cost of labor. Maintenance (labor, supervision, and materials) is estimated to be 4 percent of the capital cost, and supplies are estimated to be 15 percent of labor and materials. Plant overhead is estimated to be 50 percent of operations and maintenance, and payroll overhead is estimated to be 20 percent of operating labor. No working capital is included.

Table B-3 shows the format used for total annual operating costs. Table B-4 shows some of the unit costs used in this study. The user can substitute his/her own costs if desired.

DATA INPUT

The required data must be input on the terminal or remote keyboard or be punched on cards. The card identification numbers for insertion are shown in the card inputs for batch loading on a card reader at the back of this appendix.

This costing program has been designed to be as plant-specific as possible by permitting the use of input data and conditions that are cost-related to the plant or its geographical area. If an input variable is undefined by the user, the program uses a base number (as defined in Table B-5).

The input data consist of:

- System name: Limestone, lime, magnesium oxide, citrate
- Gas flow rate: 50,000 to 400,000 scfm
- Gas temperature: 127° to 650°F
- SO_2 content: Up to 3.5%
- Percent moisture in the gas stream (If unknown, use 2.2 percent by weight at 600°F and 6 percent at 350°F.)
- Maximum sulfur dioxide removal efficiency

Limestone	85%
Lime	90%
Magnesium oxide	92%
Citrate	95%

TABLE B-3. FORMAT FOR TOTAL ANNUAL OPERATING COSTS

1. Raw materials:

   Lime
   Limestone
   MgO
   Citrate
   Fixation chemicals--lime
   Sulfuric acid (98%)
   Soda ash

2. Utilities:

   Water
   Electricity
   Oil

3. Operations:

   Direct operational labor
   Supervision (percentage of direct operational labor)

4. Maintenance

   Labor and materials (percentage of total capital cost of installation)
   Supplies (percentage of labor)

5. Overhead

   Plant (percentage of operations and maintenance)
   Payroll (percentage of labor)

6. Fixed costs

   Depreciation (straight-line percentage)
   Taxes and insurance (percentage of total capital costs of installation)
   Cost of capital (interest rate on borrowed capital)

7. Trucking costs (contracted cost for removal of sludge a distance of 5 miles, if required)

Total Annual Operating Cost is sum of items 1 through 7.

TABLE B-4. UNIT COSTS

Item	Cost
Chemicals:	
Lime	\$ 50/ton
Limestone	10/ton
MgO	250/ton
Citrate	990/ton
Sulfuric acid (98%)	70/ton
Soda ash	105/ton
Fixation chemicals-lime	50/ton
Utilities:	
Water	\$0.35/1000 gal
Electricity	40 mills/kWh
Oil	\$1/gallon
Operations:	
Labor rate	\$9.60/man-hour
Supervision	15% of labor rate
Maintenance:	
Maintenance labor and materials	4%[a]
Supplies	15% of maintenance and labor and materials
Plant overhead	50% of operations and maintenance
Plant payroll	20% of labor
Depreciation (12.5 years)	8.0%[a]
Taxes and insurance	2.3%[a]
Cost of capital	10%[a]
Trucking costs	\$2.785/yd^3

[a] Percentage of total capital costs of installation.

TABLE B-5. BASE INPUT NUMBERS

	Known:	If unknown use:	Option:
Gas flow, scfm	X		
Gas temperature, °F	X		
Percent SO_2 content	X		
Percent moisture	X	2.2% at 600°F, 6% at 350°F	
Efficiency required	X	Lime 90%, limestone 85% MgO 92%, citrate 95%	
Plant life, years	X	12½	
Days storage	X	30 days minimum	
Bypass to stack			Yes or No
Venturi			If particulate removal is required
Reheat	X	50°F reheat if all gases scrubbed	
Stack, new			Yes or No
Precooler		If over 400°F	If desired
Soilds disposal (select one for lime and limestone)			
Direct to pond Thickener/pond Thickener/vacuum filter Thickener/centrifuge Oxidation/thickener centrifuge (gypsum) Oxidation/thickener/ vacuum filter (gypsum)			

(continued)

TABLE B-5 (continued)

	Known:	If unknown use:	Option:
Installation factor (select one)			
Moderate		1.0	
Moderately difficult		1.16	
Difficult		1.30	
Material costs (see Table B-4 if unknown)			
Capital costs	X	10%	
Taxes and insurance	X	2.3%	
Contingency	X	1.5%	
Years to construct	X	2.5	
If MgO or Citrate, liquid SO_2 plant			Yes or No
If C.E. Index, a year from 1970 through 1982			Select year
After mid-1981			Calculate per Cost Index
Output listing (select one)			
Capital and annual costs only			
Capital and annual costs plus equipment listing			

Note: if a smaller percentage of SO_2 removal is required for compliance, determine amount of gas that must be scrubbed and use the gas flow calculated with the efficiencies shown to determine costs. The user will direct the remainder of the unscrubbed gases to the bypass ducting.

- Life span of the removal system (If unknown, use 12-1/2 years.) Depreciation is computed on a straight-line basis, based on the life of the system.
- Days of fresh absorbent storage planned (If unknown, use 30 days for all systems.)
- Bypass ducting to stack for partial SO_2 removal or emergency
- Venturi scrubber (if particulate removal is required)
- Stack (if new one is required for system)
- Cooling or spray chamber (if temperature is above 400°F)
- Reheat scrubbed gases to between 50° and 177°F. If only partial scrubbing is required, reheat may not be required.

If the user selects a limestone or lime system, one (and only one) of six options must be specified for disposal of the calcium sulfite/sulfate byproduct.

1. Bleed stream to pond only
2. Bleed stream to thickener and then to pond
3. Bleed stream to thickener and vacuum filter and then truck to disposal area
4. Bleed stream to thickener and centrifuge and then truck to disposal area
5. Bleed stream to oxidation, thickener, and centrifuge, and then truck to disposal or disposable area (gypsum)
6. Bleed stream to oxidation, thickener, and vacuum filter, and then truck to disposal or storage area

If the user selects a magnesium oxide or citrate system, the following option may be selected for disposal of sulfur dioxide:

- Liquid SO_2 plant

Other variables for all the systems include:

- One of the following types of retrofit: 1) easy installation (sufficient space available with minor changes to existing/new ducting);* 2) moderately difficult installation (sufficient space available, but major changes to ducting and other plant interferences such as wiring, water runs, etc.; 3) difficult installation (space for installation is crowded and major changes required to existing ducting, etc.)
- Years estimated to design and construct (If unknown, use 2.5 years.)
- Contingency (If unknown, use 15 percent.)
- Water (If unknown, use $0.35 per 1000 gallons.)
- Electricity (If unknown, use 40 mills per kWh.)
- Oil (If unknown, use $1.00 per gallon.)
- Labor (If unknown, use $9.60 per hour.)
- Insurance and taxes (If unknown, use 2.3 percent.)
- Capital cost or interest on borrowed money (If unknown, use 10 percent.)
- Raw material costs (If unknown, use $50/ton for lime, $10/ton for limestone, $250/ton for MgO, $990/ton for citrate, $105/ton for soda ash, $30/ton for sulfuric acid from the smelter, and $70/ton for sulfuric acid from a supplier.)
- Chemical Engineering Cost Index for the years 1970 through 1980 and the average for the period January through July 1981 are shown. Select year required or insert indexes for the specific time desired.

DATA OUTPUT FORMATS

The data output can be requested to show "Capital and Annual Costs" or "Capital and Annual Costs With Equipment Listing." If more than one flow or SO_2 value is required, the costs can also be given (if desired) in a tabular listing for each specific system, e.g., lime, limestone, MgO, citrate (see Table B-5).

---

* New installation is similar to the easy retrofit.

The program based on input variables will give the following information:

- Installed Field Costs corrected to year or time period indicated by the user and reference index for the following process areas:

Description	Lime	Limestone	MgO	Citrate
Materials handling	x	x	x	x
Feed preparation	x	x	x	x
Precooler*	x	x	x	x
Venturi* and absorber	x	x	x	x
Reheat* and stack*	x	x	x	x
Solids disposal	x	x	x	x
Emergency, cooling, or disposal pond	x	x	x	x
Regeneration			x	x
Liquid SO_2			x	x

*If required.

- Indirect Costs
  - Engineering, administration, and overhead; field supervision, inspection, temporary construction, rental of equipment, freight, offsites, taxes, and spares
  - Interest during construction [cost of capital (if unknown, use 10%) x years (if unknown, use 2.5) x 0.325 x capital]
  - Contingency
- Cooling pond liner
- Total capital costs
- Equipment list showing area, item, quantity, and installed cost as of July 1981 and corrected to the time period requested
- Pond size - emergency, cooling, and disposal
- Annual operating costs:
  - Raw materials
  - Utilities
  - Operating labor
  - Maintenance
  - Overhead

  - Fixed costs: depreciation; taxes and insurance; capital costs (This can be made zero, if user decides no borrowing is necessary.)
  - Total annual operating costs

- Total energy requirements

For each case that has a precooler or liquid SO_2, two sets of output will be printed. One will be costed with a cooling pond; the other will be costed with a cooling tower. The user decides which cooling system is better suited to the plant. If space is tight, the precooler with a cooling tower might be a better choice rather than the cooling pond, even if the tower is more expensive.

The user can also obtain a summary listing of capital and annual costs for each system. If the user is on the terminal, the summary question is asked at the beginning of each system. If the user is running cards, the summary question needs only to be specified one time for each system. The summary listing for each specific system is indicated in the first case of the following system. For example, if four lime and four MgO cases are run, the summary listing for the lime is indicated in the first MgO case. Since nothing follows the last system, two blank cards are required to run the program. The summary listing is indicated on these cards in the same manner as before. Two blank cards are always required, even if a summary listing of the last system is not wanted.

A program listing and example output are presented on the following pages.

SMELTER PROGRAM INITIATION

After a RUN has been initiated, the following statement will execute the program:

```
@XQT SMT*SMELTER.MAIN
```

Then enter a 0(zero) if access is via a terminal, or a 1 if access is via punched cards.

All printed (non-terminal) output is sent to NCC Printer 1250 (8 1/2 x 11 plain white forms).

To exit the program in terminal mode, enter "X" in response to the request for a system name.

To exit the program in batch (cards) mode, place 2 blank cards after the last of the data cards.

```
SMT*SMELTER(1).MAIN(22)
      CHARACTER SYSTEM*10
      CHARACTER*30 IFCLIS(15)
      DIMENSION AC(13),QUAN(4),XC(2,4),XCF(3)
      COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID
     &,RICNTG,XC,XCF,RTI,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,IBYPAS,IRET
      COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPMSO2,SO2AB,PPMSIN
     *                 ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPMH2O,PPMAIR,
     *                 PPMTOT,PPMABU,PPMABN
      COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
     *                  JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
      COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
     *                   ,TOTC
      COMMON /COM05/PREC,NXOT,IENTRY,NOUT,NXX4,NXX5,AC,QUAN,
     *          ALPHA,XX4,XX5
      COMMON /COUL/ ITWR
      IERR= 0
      NOUT= 0
C
C     OPEN EQUIPMENT FILE
      OPEN(3,FILE='SMT*SMELTRDA',STATUS='OLD',ACCESS='DIR',FORM=
     &     'FORMATTED',RECL=80,ERR=99990)
C
C     OPEN SUMMARY FILE
      IERR= FACSF('@CAT,P SMT*SUM(+1). . ')
      IF(IERR .GT. 0) GO TO 99999
      IERR= FACSF('@ASG,A SMT*SUM. . ')
      IF(IERR .GT. 0) GO TO 99999
      OPEN(10,FILE='SMT*SUM',STATUS='OLD',ACCESS='DIR',FORM=
     &     'UNFORMATTED',RECL=5,ERR=99990)
C
C     INITIALIZE SUMMARY FILE
C
      DO 5 I=1,151,50
    5 WRITE(10'I) (0.0,J=1,5)
C
C     OPEN LIST FILE
C
C     OPEN ESCALATION INDEX FILE
      OPEN(15,FILE='SMT*SMTESCDA',STATUS='OLD',ACCESS='DIR',FORM=
     &     'FORMATTED',RECL=80,ERR=99990)
C
C     DETERINE IF ACCESS IS BATCH OR INTERACTIVE
      IENTRY=0
      READ(5,*) IENTRY
C
C     READ INPUT DATA
   10 CALL SMTRDN
      IF(IEXIT.EQ.1)GO TO 9999
C
C     OPEN ALTERNATE PRINT FILE
C
      IF(NOUT .NE. 2) GO TO 50
      IERR= FACSF('@CAT,P SMT*PRNT(+1). . ')
      IF(IERR .GT. 0) GO TO 99999
      IERR= FACSF('@ASG,A SMT*PRNT. . ')
      IF(IERR .GT. 0) GO TO 99999
      OPEN(2,FILE='SMT*PRNT.',ACCESS= 'SEQ',TYPE='APRNTA',
     &STATUS='OLD',FORM='FORMATTED',MRECL=80,ERR=99990)
C
C     PRINT INPUT SUMMARY
   50 CALL SMTINS
      CALL SMTFLW
C
C     BRANCH TO SI ZING ROUTINE FOR PARTICULAR SYSTEM
      GO TO (100,200,300,400),ISYS
  100 CALL SMTLM1
      CALL SMTEQP
      CALL SMTLM2
      GO TO 500
  200 CALL SMTMG1
      CALL SMTEQP
      GO TO 500
  300 CALL SMTLS1
      CALL SMTEQP
      CALL SMTLS2
      GO TO 500
  400 CALL SMTCT1
      CALL SMTEQP
  500 CONTINUE
C
C     SIZE VENTURI (IF NECCESSARY)
      IF(IVENT .EQ. 1) CALL SMTVEN
C
C     WRITE REPORT
      L = 2
      IF(PREC .EQ. 0. .AND. LIQUID .EQ. 0 .OR. GPM .LT. 10650.) L = 1
      DO 600 ITWR=1,L
      CALL SMTPON
  600 CALL SMTRPT
      DO 700 I=1,300
  700 NEQUIP(I)=0
      GO TO 10
 9999 CONTINUE
C
C     CLOSE FILES
C
      CLOSE(10,STATUS='DELETE',ERR=99990)
      IF(NOUT .EQ. 6) STOP
       CLOSE(2,ERR=99990)
      IERR= FACSF('@FREE SMT*PRNT. . ')
      IF(IERR .GT. 0) GO TO 99999
      IERR= FACSF('@SYM,U SMT*PRNT.,,PR1250 . ')
      IF(IERR .GT. 0) GO TO 99999
      STOP
99990 PRINT *,' ** FILE OPEN/CLOSE ERROR **'
99999 PRINT *, ' ** PROGRAM ABORTED'
      PRINT 99998,' ERROR CODE =',IERR
99998 FORMAT(A14,012)
      STOP
      END
**
```

```
SMT*SMELTER(1).AC1(16)
              SUBROUTINE SMTAC1
        C
        C     THIS SUBROUTINE CALCULATES ALL ANNUAL COSTS
        C
              DIMENSION XF(4),AC(13),QUAN(4),XC(2,4),XCF(3)
              DIMENSION XCON(2,6),XABN(2,6),XWAT(2,6)
              DIMENSION XP(6),XAA(2,6)
              CHARACTER SYSTEM*10,CEI*3
              CHARACTER*30 IFCLIS(15)
              COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID
             &,RICNTG,XC,XCF,RTI,RCAP,PLIFE,NDAY,ISOLID,YCON,IVENT,
             &IBYPAS,IRET
              COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPHSO2,SO2AB,PPMSIN
             *                   ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPHH2O,PPHAIR,
             *                   PPHTOT,PPHABU,PPHABN
              COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
             *                    JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
              COMMON /COM04/6PM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
             *                     ,TOTC
              COMMON /COM05/PREC,NXOT,IENTRY,NOUT,NXX4,NXX5,AC,QUAN,
             *         ALPHA,XX4,XX5
              COMMON/CITRAT/ SA,CIT,OIL,SAQ,CITQ,OILQ,SAC,CITC,OILC
              COMMON /COM06/ IBYR,CEI(6),IRYR(6),RTOTAL(15),RSTOT,
             &        RTOTD,RTOTI,RACLNK,IRYRLN,RTOTC,NCEI(15)
              COMMON /COOL/ ITWP
              DATA XF/209.25,5859. ,92.22,1./
              DATA XWAT/.003,.0017,.0094,.0054,.0094,.0054,.0094,.0054,
             &        .0014,.000806,.0014,.000806/
              DATA XABN/.0033,.000302,.0080,.0057,.0090,.0064,.0119,
             &      .0080,.0287,.0165,.0315,.0182/
              DATA XP/.668,.664,.692,.671,.694,.669/
              DATA XCON/.373,187.6,.373,187.6,.373,187.6,5.57,191.9,.373,
             &          187.6,5.57,191.9/
              DATA XAA/.1144,.1144,.1234,.120,.3026,.241,.1187,.116,.3035,
             &         .232,.1201,.117/
              QUAN(1)=0.0
        C
        C     RAW MATERIAL
              IF(ISYS .NE. 4) QUAN(1)=SCFM*DSO2/XF(ISYS)
              IF(ISYS.NE.4)GO TO 10
              CITQ=SCFM*DSO2/516746.
              SAQ=SCFM*DSO2/64593.
        C
        C     FIXATION CHEMICAL
           10 IF(ISYS .EQ. 1 .AND. ISOLID .GE. 5)QUAN(2) = PPHSO2/178570.
              IF(ISYS .EQ. 3 .AND. ISOLID .GE. 5) QUAN(2)=PPHSO2/168650.
        C
        C     SULFURIC ACID
              IF((ISYS .EQ. 2 .OR. ISYS .EQ. 4) .AND. LIQUID .EQ. 1)
             & QUAN(2)=SO2AB/64.*.0842*18.*.7/.28/2000.
        C
        C     UTILITIES
        C     WATER
              QUAN(3)=((.00000326*DEGF+.006577)*H2OCON+.000195*
             &         DEGF-.023101)*PPHAIR/(8.33*60.)
              IF (ISYS .EQ. 1)QUAN(3)=QUAN(3)+PPHABN*XWAT(1,ISOLID)
```

```
      IF(ISYS .EQ. 2) QUAN(3)= QUAN(3) + .025*SCFM*DSO2
      IF (ISYS .EQ. 3)QUAN(3)=QUAN(3)+PPHABN*XWAT(2,ISOLID)
      IF (ISYS .EQ. 4)QUAN(3)=QUAN(3)+.000681*SCFM
      IF(LIQUID .EQ. 1 .AND. ISYS .EQ. 2) QUAN(3)=QUAN(3)+.0178*SO2AB
      IF(LIQUID .EQ. 1 .AND. ISYS .EQ. 4) QUAN(3)=QUAN(3)+.0000941*SO2AB
      IF (PREC .EQ. 1.OR. DEGF .GE. 400.)QUAN(3)=QUAN(3)+.020*GPM
C
C     ELECTRICITY
      IF (ISYS .EQ. 1)QUAN(4)=PPHABN*XABN(1,ISOLID)+SCFM
     &*.00475+.00567*SCFM**.668
     &+XCON(1,ISOLID)+XAA(1,ISOLID)*PPHABN**XP(ISOLID)
      IF(ISYS.EQ.2) QUAN(4)=SCFM*.00475+.00567*SCFM**.668+.0142*PPHABN
     &+5.1240+.4557*PPHABN**.6572
      IF(ISYS .EQ. 3)QUAN(4)=PPHABN*XABN(2,ISOLID)+SCFM
     &*.00542+.0090*SCFM**.668+XCON(2,ISOLID)+XAA(2,ISOLID)*PPHABN**XP(I
     &SOLID)
      IF(ISYS .EQ. 4)QUAN(4)=SCFM*.00550+.004664*SCFM**.666
      IF(LIQUID .EQ. 1 .AND. ISYS .EQ. 2)QUAN(4)=QUAN(4)+.1799*SO2AB
      IF(LIQUID .EQ. 1 .AND. ISYS .EQ. 4)QUAN(4)=QUAN(4)+.0221*
     &      SO2AB+.75
      IF(ITWR .EQ. 2) QUAN(4)=QUAN(4) + GPM*0.0190
      IF(PREC .EQ. 1 .OR. DEGF .GE. 400.)QUAN(4)=QUAN(4)+GPM*.067
     &+SCFM*.000639
      IF(IVENT .EQ. 1)QUAN(4)=QUAN(4)+SCFM*.0032
C
C     OIL
      OILQ = 0.0
      IF(ISYS .EQ. 2)OILQ=(EQUIPS(94)+EQUIPS(197))*60 *.8795
C
      IF(ISYS .NE. 4) GO TO 15
      CITC=CITQ*8400.*CIT
      SAC=SAQ*8400.*SA
      CALL SMTRO(CITC,100.)
      CALL SMTRO(SAC,100.)
      AC(1)=CITC+SAC
      WQUAN=6.0*SO2AB*970.0*1.27/7500.0
      QUAN(3) = QUAN(3) + (WQUAN*0.01)
      QUAN(4) = QUAN(4) + (WQUAN*0.746/55.44)
      GO TO 20
C
   15 AC(1) = QUAN(1) * 8400. * XC(1,ISYS)
   20 AC(2) = QUAN(2) * 8400. * XC(2,ISYS)
      AC(3) = QUAN(3) * 8400. * .001*XCF(1)*60.
      AC(4) = QUAN(4) * 8400. * .001 * XCF(2)
      OILC  = OILQ    * 8400. * OIL
      CALL SMTRO(OILC,100)
C
C     OPERATING LABOR
C     DIRECT
      AC(5) = 43646.2*XCF(3)
      IF(ISYS.EQ.2) AC(5) = 52615.4*XCF(3)
      IF(ISYS.EQ.4) AC(5) = 35076.9*XCF(3)
      IF(LIQUID.EQ.1)AC(5)=AC(5)+17538.5*XCF(3)
C     SUPERVISION
      AC(6) = .15*AC(5)
C
C     MAINTENANCE - LABOR AND MATERIALS
      AC(7)= 0.04 * RTOTC
C
```

```
C     SUPPLIES
      AC(8) = 0.15 * AC(7)
C
C     OVERHEAD - PLANT
      AC(9) = 0.50 * ( AC(5) + AC(6) + AC(7) + AC(8) )
C
C     PAYROLL
      AC(10) = 0.20 * (AC(5) + AC(6) )
C
C     FIXED COSTS
C
C     DEPRECIATION (STRAIGHT LINE)
      DEPREC= RTOTC/PLIFE
C
C     TAXES AND INSURANCE
      TAXINS=RTI*RTOTC
C
C     CAPITAL COST
      CAPCOS=RCAP*RTOTC
C
      AC(11)=DEPREC+TAXINS+CAPCOS
C
C     TRUCKING
      IF(ISYS .EQ. 1.AND.ISOLID .GE. 3)AC(12)=PPHABN*1.94/.6*8400.
     */(62.4*1.47*27.*10.)*27.85
      IF (ISYS .EQ. 1.AND.ISOLID .GE. 5) AC(12)=.6/.8*1.47/1.81*AC(12)
      IF(ISYS .EQ. 3.AND.ISOLID .GE. 3)AC(12)=PPHABN*1.12/.6*8400.
     */(62.4*1.61*27.*10.)*27.85
      IF (ISYS .EQ. 3.AND.ISOLID .GE. 5)AC(12)=.6/.8*1.61/1.88*AC(12)
      IF((ISYS.EQ.2).OR.(ISYS.EQ.4).OR.(ISOLID .LT. 3)) AC(12)=0.
C
C     TOTAL ANNUAL COST
      AC(13) = 0.
      DO 100 I=1,12
      CALL SMTRO(AC(I),100.)
  100 AC(13) = AC(13) + AC(I)
      RETURN
      END
**
```

```
SMT*SMELTER(1).AC2(7)
      SUBROUTINE SMTAC2
C
C        THIS SUBROUTINE PRINTS OUT A SUMMARY OF ALL ANNUAL COSTS.
C
C
      DIMENSION AC(13),QUAN(4),IQUAN(4),XC(2,4),XCF(3)
      CHARACTER SYSTEM*10
      CHARACTER*30 IFCLIS(15)
      CHARACTER*30 ULABEL(10),DATE*8
      CHARACTER*20 CAT(7),SUBCAT(19)
      CHARACTER*12 UCOST(3)
      COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,RICNTG,XC,
     &XCF,RT1,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,IBYPAS,IRET
      COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPHSO2,SO2AB,PPMSIN
     *               ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPHH2O,PPHAIR,
     *               PPHTOT,PPHABU,PPHABN
      COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
     *               JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
      COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
     *                ,TOTC
      COMMON /COM05/PREC,NXOT,IENTRY,NOUT,NXX4,NXX5,AC,QUAN,
     *        ALPHA,XX4,XX5
      COMMON/CITRAT/ SA,CIT,OIL,SAQ,CITQ,OILQ,SAC,CITC,OILC
      COMMON /HEAD/ IPAGE,DATE
      DATA IQUAN/5,6,5,4/
      DATA CAT /'RAW MATERIALS       ','UTILITIES           ',
     2          'OPERATING LABOR     ','MAINTENANCE         ',
     3          'OVERHEAD            ','FIXED COSTS         ',
     4          'TRUCKING COSTS      '/
      DATA SUBCAT /'LIME                ','MAGNESIUM OXIDE     ',
     2             'LIMESTONE           ','SULFURIC ACID       ',
     3             'FIXATION CHEMICALS  ','   (PH CONTROL)     ',
     4             'WATER               ',
     5             'ELECTRICITY         ','DIRECT LABOR        ',
     6             'SUPERVISON          ','LABOR AND MATERIALS ',
     7             'SUPPLIES            ','PLANT               ',
     8             'PAYROLL             ','DEPRECIATION        ',
     1             'TAXES & INSURANCE   ','CAPITAL COST        ',
     ?             '                    ','OIL                 '/
      DATA UCOST/'8400 HR/YR  ','            ',' MEN/SHIFT  '/
      DATA ULABEL /'15% OF DIRECT LABOR           ',
     2' 4% OF FIXED INVESTMENTS       ','15% OF LABOR AND MATERIALS    ',
     3'50% OF OPERATION & MAINTENANCE','20% OF OPERATING LABOR        ',
     4'% OF FIXED INVESTMENT         ','$27.85/10 CUBIC YARDS         ',
     5'     NONE                     ','    TOTAL ANNUAL COST         '
     6,'                             '/
C
C     PRINT OUT SYSTEM DESCRIPTION
      IPAGE=IPAGE+1
      WRITE(NOUT,3)  IPAGE,DATE
      WRITE(NOUT, 5) SYSTEM,SCFM,PSO2,EFF
    3 FORMAT(1H1,'PAGE ',I4,T67,A8)
    5 FORMAT ('0',T11,'SYSTEM DESCRIPTION: ',A10//
     2 T11,'SYSTEM VARIABLES:',T31,'SCFM:',F8.0,/,T31,'%SO2:',F5.2,/,
     3 T11,'SO2 CONCENTRATIONS:',F4.0,' % ABSORBED')
C
```

```
C ** PAW MATERIALS **
      WRITE(NOUT,10)
      WRITE(NOUT,20) CAT(1)
      IF (ISYS.NE.4)
     2WRITE(NOUT,30) SUBCAT(ISYS),QUAN(1),UCOST(1),XC(1,ISYS),AC(1)
      IF (ISYS.EQ.4)  WRITE(NOUT,33) CITQ,UCOST(1),CIT,CITC,SAQ,
     2               UCOST(1),SA,SAC
      IF (ISYS.EQ.1.OR.ISYS.EQ.3.OR.LIQUID.EQ.1) WRITE(NOUT,30)
     2SUBCAT(5-LIQUID),QUAN(2),UCOST(1),XC(2,ISYS),AC(2),
     &  SUBCAT(6+LIQUID*12)
C
C ** UTILITIES **
      WRITE(NOUT,20) CAT(2)
      WRITE(NOUT,31) SUBCAT(7),QUAN(3),UCOST(1),XCF(1),AC(3)
      WRITE(NOUT,32) SUBCAT(8),QUAN(4),UCOST(1),XCF(2),AC(4)
      IF(ISYS .EQ. 2) WRITE(6,34) SUBCAT(19),OILQ,UCOST(1),OIL,OILC
C
C ** LABOR **
      WRITE(NOUT,20) CAT(3)
      MEN=IQUAN(ISYS)
      IF (LIQUID.EQ.1) MEN=MEN + 2
      WRITE(NOUT,35) SUBCAT(9),MEN,UCOST(3),XCF(3),AC(5)
      WRITE(NOUT,45) SUBCAT(10),ULABEL(1),AC(6)
C
C ** MAINTENANCE AND OVERHEAD **
      DO 100 I=4,5
      J=2*I
      WRITE(NOUT,20) CAT(I)
      WRITE(NOUT,45) SUBCAT(J+3),ULABEL(J-6),AC(J-1)
      WRITE(NOUT,45) SUBCAT(J+4),ULABEL(J-5),AC(J)
  100 CONTINUE
C
C ** FIXED COST **
      WRITE(NOUT,20) CAT(6)
      WRITE(NOUT,50) SUBCAT(15),(100./PLIFE)
      WRITE(NOUT,50) SUBCAT(16),RTI*100.
      WRITE(NOUT,50) SUBCAT(17),RCAP*100.
  300 CONTINUE
      WRITE(NOUT,55) (100./PLIFE+(RTI+RCAP)*100.),ULABEL(6),AC(11)
      IF(ISYS.EQ.1.OR.ISYS.EQ.3)WRITE(NOUT,65) CAT(7),ULABEL(7),AC(12)
      WRITE(NOUT,70)
C
C ** TOTAL ANNUAL COSTS **
      WRITE(NOUT,75) ULABEL(9),AC(13)
   10 FORMAT(' ',T35,'QUANTITY',T48,'UNIT COST',T67,'ANNUAL COST')
   20 FORMAT('0',T11,A20)
   30 FORMAT(' ',T11,A20,F6.2,' T/H ',A12,F6.2,' $/TON',F12.0)
   33 FORMAT(' ',T11,'CITRIC ACID',9X,F7.4,' T/H',A12,F7.2,' $/TON',
     &F12.0,/T11,'SODA ASH',12X,F7.4,' T/H',A12,F7.2,' $/TON',F12.0)
   31 FORMAT(' ',T11,A20,F6.0,' GPM ',A12,F5.2,' $/MGAL',F12.0)
   32 FORMAT(' ',T11,A20,F6.0,' KW  ',A12,F3.0,' MILLS/KWH',F11.0)
   34 FORMAT(' ',T11,A20,F6.0,' GPH ',A12,F5.2,' $/GAL ',F12.0)
   40 FORMAT(' ',T11,A20,A30)
   35 FORMAT (' ',T11,A20,I11,A12,F5.2,' $/H/MAN ',T67,F11.0)
   45 FORMAT (' ',T11,A20,2X,A30,4X,F11.0)
   50 FORMAT(' ',T11,A20,3X,1H(,F4.1,2H%))
   55 FORMAT(' ',T30,'SUM= ',F4.1,A30,T67,F11.0)
```

```
 75 FORMAT(' ',T30,A30,T65,F13.0,/T30,'(BASED ON REVISED COSTS)')
 65 FORMAT ('0',T11,A20,2X,A30,4X,F11.0)
 70 FORMAT(' ',T67,11('=') )
    RETURN
    END
**
```

```
SMT*SMELTER(1).BD(4)
      BLOCK DATA
      DIMENSION XC(2,4),XCF(3)
      CHARACTER SYSTEM*10,SYSSAV*10
      CHARACTER*30 IFCLIS(15),CEI*3
      CHARACTER DATE*8
      COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID
     &,RICNT6,XC,XCF,RTI,RCAP,PLIFE,NDAY,ISOLID,YCON,IVENT
     &,IBYPAS,IRET
      COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPHSO2,SO2AB,PPMSIN
     *                ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPHH2O,PPHAIR,
     *                PPHTOT,PPHABU,PPHABN
      COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
     *                 JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
      COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
     *                  ,TOTC
      COMMON /COM06/ IBYR,CEI(6 ),IRYR(6),RTOTAL(15),RSTOT,
     &     RTOTD,RTOTI,RACLNR,IRYRLN,RTOTC,NCEI(15)
      COMMON /COM07/ SYSSAV,ISAV,I1
      COMMON /HEAD/ IPAGE,DATE
      DATA I1/0/
      DATA IPAGE/0/
      DATA NCEI/4,3,2,3,3,4,4,5,5,3,3,4,3*0/
      DATA TOTAL/15*0.0/
      DATA JMIN/0,49,108,13 ,3*13,141,34,69,34,155,163,185,166,198,
     &173,201,201,201,201,211,223,217,223,223,0,0,12*0/
      DATA JMAX/13,65,130,34,3*34,154,49,104,49,163,166,196,184,
     &200,184,211,211,211,211,217,226,226,226,226,0,0,12*0/
      DATA SYSSAV /'XXXXXXXXXX'/
      DATA CEI/'PI ','EMS','FF ','PM ','CL ','PC '/
      DATA IFCLIS/'MATERIALS HANDLING            ',
     2'FEED PREPARATION              ','PRE-COOLER                    ',
     3'SO2 SCRUBBING                 ','REHEAT AND STACK              ',
     4'SOLIDS DISPOSAL               ','MGO REGENERATION              ',
     5'EMERGENCY POND                ','COOLING POND                  ',
     6'CITRATE REGENERATION          ','LIQUID SO2                    ',
     7'PURGE STREAM REGENERATION     ','DISPOSAL POND                 ',
     8'SO2 SCRUBBING/VENTURI         ','                              '/
C
C     DEFAULTS  (NOT CURRENTLY USED)
C     DATA XC/60.,60.,217.,0.,10.,60.,1100.,0./
C     DATA XCF/.35,40.,9.6/
C     DATA YCON/12.57/,RTI/.02/,RCAP/.10/
C     DATA PLIFE/10./,NDAY/30/
C
C     DATA IRYR/6*81/,RICNT6/.15/
      END
**
```

```
SMT*SMELTER(1).CST(1)
              SUBROUTINE SMTCST
        C
        C          THIS PROGRAM COMPUTES THE INSTALLED FIELD COST FOR EACH
        C      EQUIPMENT ITEM (EXCEPT PONDS) AND TOTALS ALL CAPITAL COSTS
        C      (INCLUDING INDIRECTS).
        C
        C
              DIMENSION XMULT(7,2,4),XC(2,4),XCF(3),RET(3)
              CHARACTER*30 ITEM
              CHARACTER SYSTEM*10
              CHARACTER*30 IFCLIS(15)
              DIMENSION AC(13),QUAN(4)
              COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,
             &RICAT6,XC,XCF,RTI,RCAP,PLIFE,NDAYS,ISOLID,VCON,IVENT,IBYPAS,IRET
              COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPHSO2,SO2AB,PPMSIN
             *                ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPHH2O,PPHAIR,
             *                PPHTOT,PPHABU,PPHABN
              COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
             *                 JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
              COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
             *                   ,TOTC
              COMMON /COM05/PREC,NXOT,IENTRY,NOUT,NXX4,NXX5,AC,QUAN,
             *         ALPHA,ACLNR,XX5
              DATA XMULT/1.7949, 1.6626, 1.8463, 2.8926, 1.4457, 1.6928, 0.0,
             *              1.7940, 1.6619, 1.8454, 2.8919, 1.4496, 1.6560, 0.0 ,
             *              2.5447, 2.4577, 1.8463, 2.8926, 1.4457, 2.411, 1.486,
             *              2.5406, 2.4566, 1.8454, 2.8919, 1.4496, 2.402, 1.488,
             *              1.5576, 1.7635, 1.8463, 3.1303, 1.4457, 1.9508, 0.0,
             *              1.5565, 1.7633, 1.8454, 3.1296, 1.4496, 1.9492, 0.0,
             *              1.4650, 0.0000, 1.8463, 2.7977, 1.4457, 1.465 , 2.2090,
             *              1.3890, 0.0000, 1.8454, 2.7970, 1.4496, 1.389 ,2.2090/
              DATA RET/1.0,1.16,1.3/
              DO 1 I=1,7
            1 TOTAL(I)=0.0
              DO 3 I=10,15
            3 TOTAL(I)=0.0
              DO 2 I=1,9
            2 IPT(I,30)=0
        C
        C     COST EQUIPMENT
           30 DO 1000 L=1,7
        C
        C     OBTAIN RANGES IN EQUIPMENT FILE FOR SYSTEM
              IF(L .EQ. 7 .AND. ISYS .GE. 3) GO TO 1000
              J1=JMIN(ISYS,L)+1
              J2=JMAX(ISYS,L)
              DO 300 J=J1,J2
              IF(NEQUIP(J) .EQ. 0) GO TO 300
        C
        C     READ ITEM NAME, COSTING CONSTANTS, AND EQUIPMENT CATEGORY (ICAT)
              READ(3'J,310) ITEM,BCOST,BSIZE,F,ICAT
          310 FORMAT(A30,2F10.0,F5.0,I5)
        C
        C     SET ICAT FILE POINTER ARRAY
              IPT(ICAT,30)=IPT(ICAT,30)+1
              IF(IPT(ICAT,30) .EQ. 30) STOP ' POINTER OVERFLOW'
```

```
      IPT(ICAT,IPT(ICAT,37))=J
      IF(NXOT .EQ. 3)WRITE(NOUT,66)J,EQUIPS(J),NEQUIP(J)
   66 FORMAT(1X,I3,F15.2,I4)
      COST(J)=BCOST*((EQUIPS(J)/BSIZE)**F)*NEQUIP(J)
C
C     MULTIPLY COST BY INSTALLATION FACTOR
C    (NO INSTALLATION FACTORS FOR DUMP TRUCKS AND FRONT END LOADERS)
      IF(J .EQ. 47 .OR. J .EQ. 114) GO TO 305
      COST(J) = COST(J) * XMULT(ICAT,ISTACK,ISYS)
      IF(J .GE. 24 .AND. J .LE. 26 .AND. ISYS .GE. 3)
     &   COST(J)=COST(J)/XMULT(ICAT,ISTACK,ISYS)*XMULT(ICAT,ISTACK,1)
C
C     RETROFIT WHERE NECCESARY
  305 IF(ICAT.EQ.2.OR.ICAT.EQ.4.OR.ICAT.EQ.5.OR.ICAT.EQ.8)
     & COST(J)=COST(J)*RET(IRET)
      CALL SMTRO(COST(J),100.)
C
C     TOTAL EQUIPMENT CATEGORIES
      TOTAL(ICAT)=TOTAL(ICAT) + COST(J)
  300 CONTINUE
 1000 CONTINUE
C
      SUBTOT = 0.0
C
C     SUBTOT OF EQUIPMENT CATEGORIES
      DO 41 I = 1,7
      SUBTOT = SUPTOT + TOTAL(I)
   41 CONTINUE
C
C     ADD IN POND COSTS
      TOTALD = SUBTOT + TOTAL(8) + TOTAL(9)
C
      TOTAL(10) = TOTALD*.3125
      TOTAL(11) =(TOTALD+TOTAL(10))*RCAP*YCON*.325
      TOTAL(12) = RICNTG*(TOTALD + TOTAL(10)+TOTAL(11))
      CALL SMTRO(TOTAL(10),100.)
      CALL SMTRO(TOTAL(11),100.)
      CALL SMTRO(TOTAL(12),100.)
C
C     ADD IN INDIRECTS, INTEREST DURING CONSTRUCTION, AND CONTINGENCY
      TOTALI = TOTAL(10) + TOTAL(11) + TOTAL(12)
C
C     TOTAL CAPITAL COSTS
      TOTC = TOTALI + TOTALD
      RETURN
      END
**
```

```
SMT*SMELTER(1).CT1(3)
      SUBROUTINE SMTCT1
      CHARACTER SYSTEM*10
      CHARACTER*30 IFCLIS(15)
      DIMENSION AC(13),QUAN(4),XC(2,4),XCF(3)
      COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,
     &RICNTG,XC,XCF,RT1,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,IBYPAS,IRET
      COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPHSO2,SO2AB,PPMSIN
     *                  ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPHH2O,PPHAIR,
     *                  PPHTOT,PPHABU,PPHABN
      COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
     *                  JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
      COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
     *                   ,TOTC
      COMMON /COM05/PREC,NXOT,IENTRY,NOUT,NXX4,NXX5,AC,QUAN,
     *         ALPHA,XX4,XX5
C
C     CITRATE
C
C     ABSORBER
      NEQUIP(142)=2
      EQUIPS(142)=SCFM*22.4/1000.
      ACFM1=SCFM*587./530.
      IF(ACFM1 .LE. 438300) GO TO 1005
      EQUIPS(142)=EQUIPS(142)/2.
      NEQUIP(142)=3
C
C     ABSORBER RETENTION TANK
 1005 G=SCFM*587./530./1000.
      L=G*22.4
      EQUIPS(143)=L*10.*1.25*1.33/7.48
      IF (NEQUIP(142) .EQ. 2.)NEQUIP(143)=1
      IF (NEQUIP(142) .EQ. 3.)NEQUIP(143)=2
      CALL SMTTNK(EQUIPS(143),NEQUIP(143),EQUIPS(144),NEQUIP(144))
C
C     PUMP TO ABSORBER
      EQUIPS(145)=EQUIPS(142)
      NEQUIP(145)=NEQUIP(142)
C
C     PUMPS FROM ABSORBER
      EQUIPS(146)=EQUIPS(142)
      NEQUIP(146)=2*NEQUIP(143)
C
C     FEED PREHEATER
  200 NEQUIP(147)=1
      EQUIPS(147)= (EQUIPS(142)*500.*1.08 * 63.)/(200.*34.4*0.83)
C
C     ABSORBATE COOLER
      NEQUIP(148)=1
      EQUIPS(148)=EQUIPS(142)*500.*1.08  * 37./(200.*37.5*0.89)
C
C     STRIPPER
      NEQUIP(149)=1
      IF(PSO2 .LE. 1.25) GO TO 300
      EQUIPS(149)= 4. * SO2AB * 7.95 / (500. * 1.08)
      GO TO 400
  300 EQUIPS(149)=(-4.7*PSO2+9.9)*SO2AB*7.95/(500.*1.08)
  400 CONTINUE
C
C     REBOILER
      NEQUIP(150)=1
      IF (PSO2 .LE. 1.25)GO TO 500
      EQUIPS(150)=4.*SO2AB*970./25000.
      GO TO 600
  500 EQUIPS(150)=(-4.7*PSO2 + 9.9)*SO2AB*970./25000.
  600 CONTINUE
C
C     CONDENSER
      NEQUIP(151)=1
      EQUIPS(151) = EQUIPS(150) * 10.3
C
C *** LIQUID SO2 ***
C
      IF(LIQUID .EQ. 0) GO TO 999
C
C     70% ACID RECYCLE PUMP
      PPHWAT=SO2AB/64.*.0842*18.
      NEQUIP(153)=2
      EQUIPS(153)=(PPHWAT*3.5+(SO2AB+PPHWAT)*3.2)/(8.33*60.*1.61)
C
C     98% ACID RECIRCULATION PUMP
      NEQUIP(154)= 2
      EQUIPS(154) = (PPHWAT+SO2AB)*3.2/(8.33*60.*1.836)
C
C     BLOWER
      NEQUIP(161)= 1
      EQUIPS(161)= (SO2AB/64.+PPHWAT/18.)*386.7/60.*575./530.
C
C     PUMP TO 98% ACID STORAGE TANK
      EQUIPS(218)=(PPHWAT*2.5)*10./(8.33*60.*1.836)
      NEQUIP(218)=2
C
C     98% ACID STORAGE TANK
      EQUIPS(219)=PPHWAT*2.5*24.*30./(62.4*1.836)
      NEQUIP(219)=1
      CALL SMTTNK (EQUIPS(219),NEQUIP(219),EDUMMY,NDUMMY)
C
C     PUMP FROM 98% ACID STORAGE TANK
      EQUIPS(220)=EQUIPS(218)/10.
      NEQUIP(220)=2
C
C     DRYING TOWER
      NEQUIP(156)= 1
      EQUIPS(156)= EQUIPS(161)
C
C     ACID COOLER
      NEQUIP(157)= 1
      EQUIPS(157)=(2.5*PPHWAT*180.+PPHWAT*20.)/(40.*10.73*.96)
C
C     70%  ACID HOLD TANK
      EQUIPS(221)=3.5*PPHWAT*24./(62.4*1.836)
      NEQUIP(221)=1
      CALL SMTTNK (EQUIPS(221),NEQUIP(221),EDUMMY,NDUMMY)
C
```

```
C     PUMP FROM 70% ACID HOLD TANK
      EQUIPS(222)=EQUIPS(218)*.98/.7*1.836/1.61
      NEQUIP(222)=2
C
C     70% ACID STORAGE TANK
      EQUIPS(223)=EQUIPS(221)*30.
      NEQUIP(223)=1
      CALL SMTINK (EQUIPS(223),NEQUIP(223),EDUMMY,NDUMMY)
C
C     REFRIGERATION UNIT
      NEQUIP(158)= 1
      EQUIPS(158)= SO2AB*(0.16 * 76. + 168. + 0.3*9.)
     2   /12000.
C
C     LIQUID SO2 PUMP
      NEQUIP(159)=2
      EQUIPS(159)=SO2AB /(500.*1.38)
C
C     STORAGE RECEIVER/TANK
      NEQUIP(160)= 1
      EQUIPS(160)=EQUIPS(159) * 60. * 24. * 4./7.48
C
C     DUCTING TO DRYER
      DUCTD2=2.*SQRT(SCFM*527./530./3500./3.14159)
      DUCTL2=70.
      NEQUIP(162) = 1
      EQUIPS(162)= DUCTD2*DUCTL2*3.14159 * 16.
C
C     PURGE STREAM REGENERATION
  999 CONTINUE
      NEQUIP(163)=1
      EQUIPS(163)= SO2AB
C
      RETURN
      END
**
```

```
SMT*SMELTER(1).EQP(5)
      SUBROUTINE SMTEQP
      CHARACTER SYSTEM*10
      CHARACTER*30 IFCLIS(15)
      DIMENSION AC(13),QUAN(4),XC(2,4),XCF(3)
      COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,
     &RICHTG,XC,XCF,RTI,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,IBYPAS,IRET
      COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPHSO2,SO2AB,PPMSIN
     *                ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPHH2O,PPHAIR,
     *                PPHTOT,PPHABU,PPHABN
      COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
     *                 JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
      COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
     *                  ,TOTC
      COMMON /COM05/PREC,NXOT,IENTRY,NOUT,NXX4,NXX5,AC,QUAN,
     *         ALPHA,XX4,XX5
C
C     EQUIPMENT
C
      IF (IBYPAS .EQ. 0)GO TO 1000
C
C     DUCTING FOR BYPASS
      DUCTDO=2.*SQRT(SCFM*(460.+DEGF)/530./3500./3.14159)
      DUCTLO=300.
      EQUIPS(33)=DUCTDO*DUCTLO*3.14159*16
      NEQUIP(33)=1
C
C     DUCTING FROM ESP
 1000 DUCTD = 2.*SQRT(SCFM*(460.+DEGF)/530./3500./3.14159)
      DUCTL=100.
      EQUIPS(15)=DUCTD*DUCTL*3.14159*16.
      NEQUIP(15)=1
      IF(DEGF .GE. 400)GO TO 999
      IF(PREC .EQ. 0.) GO TO 103
C
  999 SCFMS = SCFM * DSO2
      SCFMW = SCFM * DH2O
      SCFMDA = SCFM - SCFMW - SCFMS
      QSO2 = PPHSO2 * (DEGF-127.) * 0.17
      QA   = PPHAIR  * (DEGF-127.) * 0.25
      QH2O = PPHH2O * (DEGF-127.) * 0.445
      QTOTAL = QSO2 + QA + QH2O
C
C     HOLD TANK FOR COOLING CHAMBER
      GPM = QTOTAL/17500.
      EQUIPS(16) = GPM*(10.*1.1/7.48)
      NEQUIP(16) = 1
      CALL SMTTNK(EQUIPS(16),NEQUIP(16),EDUMMY,NDUMMY)
C
C     COOLING CHAMBER
      EQUIPS(14)=ACFM*8./60.
      NEQUIP(14)=1
C
C     PUMP TO COOLING CHAMBER
      IF(GPM .GE. 10000) GO TO 1001
      EQUIPS(18)=GPM
      NEQUIP(18)=2
      GO TO 1003
 1001 IF(GPM .GE. 20000) GO TO 1002
      EQUIPS(18)=GPM/2
      NEQUIP(18)=3
      GO TO 1003
 1002 EQUIPS(18)=GPM/3.
      NEQUIP(18)=4
 1003 CONTINUE
C
C     PUMPS FOR COOLING POND/TOWER
      IF(GPM .GE. 10000)GO TO 101
      EQUIPS(17)=GPM
      NEQUIP(17)=4
      GO TO 103
  101 IF(GPM .GE. 20000)GO TO 102
      EQUIPS(17)=GPM/2.
      NEQUIP(17)=6
      GO TO 103
  102 EQUIPS(17)=GPM/3.
      NEQUIP(17)=8
  103 CONTINUE
C
C     ABSORBER
C     ABSORBER IN CITRATE SYSTEM IS SIZED IN SMCT1 SUBROUTINE
      EQUIPS(19) = SCFM*587./530.
      IF(ISYS .EQ. 4) GO TO 1005
      NEQUIP(19) = 2
      IF (EQUIPS(19).LE.300000.0) GO TO 1005
      EQUIPS(19) = EQUIPS(19)/2.
      NEQUIP(19) = 3
 1005 CONTINUE
C
C     DUCTING FROM COOLING CHAMBER
      DUCTD1=2 * SQRT(SCFM*587./530./3500./3.14159)
      DUCTL1=150.
      EQUIPS(27) = DUCTD1*DUCTL1*3.14159*16.
      NEQUIP(27) = 1
      IF (PREC .EQ. 0.) EQUIPS(27)=0
      IF (PREC .EQ. 0.) NEQUIP(27)=0.
      IF (NEQUIP(19).EQ.2.OR.EQUIPS(19).LT.438300.)
     & EQUIPS(27)=EQUIPS(27)*1.4
      IF (NEQUIP(19).EQ.3.OR.EQUIPS(19).GE.438300.)
     &    EQUIPS(27)=EQUIPS(27)*1.8
C
C     ABSORBER RECIRCULATION TANK AND AGITATOR
      IF (ISYS .EQ. 4) GO TO 1007
C     ABSORBER RECIRCULATION TANK IN CITRATE SYSTEM IS SIZED IN SMCT1PG
      G = SCFM*587./530./1000.
      L = G*30.
      IF(ISYS.EQ.3)L=L*2
      EQUIPS(20) = L * 10. * 1.25 * 1.33/7.48
      IF (NEQUIP(19) .EQ. 3) NEQUIP(20)=2
      IF (NEQUIP(19) .EQ. 2) NEQUIP(20)=1
      CALL SMTTNK(EQUIPS(20),NEQUIP(20),EQUIPS(21),NEQUIP(21))
C
C     PUMPS FOR ABSORBER
 1007 IF (ISYS .EQ. 4) GO TO 1006
```

```
C     PUMPS FOR ABSORBER IN CITRATE SYSTEM IS SIZED IN SMCT1 SUBROUTINE
      EQUIPS(22) = L/3.
      NEQUIP(22) = 4 * NEQUIP(19)
 1006 CONTINUE
C
C     MIST ELIMINATOR
      EQUIPS(24) = SCFM*587./530.
      NEQUIP(24) = 2
      IF(NEQUIP(19) .EQ. 3 .OR. EQUIPS(19) .GE. 438300.)
     & NEQUIP(24)=3
C
C     STACK FAN
      EQUIPS(25) = SCFM*587./530.
      NEQUIP(25) = 1
C
C     SOOT BLOWER
      EQUIPS(26) = 1.
      NEQUIP(26) =  EQUIPS(24)/3500./25.+1.
      NEQUIP(26)=2*NEQUIP(26)
C
C     SUMP PUMP
      NEQUIP(26) = 1
      EQUIPS(28) = 1.
C
C     DUCTING TO STACK
      DUCTD2=2*SQRT(SCFM * 637/530./3500./3.14159)
      DUCTL2=210.
      EQUIPS(30) =DUCTD2*DUCTL2*3.14159*16.
      IF (NEQUIP(19).EQ.3.OR.EQUIPS(19).GE.438300.)
     & EQUIPS(30)=1.4*EQUIPS(30)
      NEQUIP(30)=1
C
C     REHEATER
      EQUIPS(31) = .77 * SCFM * 637.0/530.0
      NEQUIP(31) = 1
C
C     BLOWER FOR REHEATER
      EQUIPS(29) = EQUIPS(31)*530./637.
      NEQUIP(29) = 1
C
C     STACK
      IF(ISTACK.EQ.1.) GO TO 5000
      NEQUIP(32) = 1
      EQUIPS(32) = SCFM*637./530.*1.77
 5000 RETURN
      END
**
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SPT*SMELTER(1).ESC(3)
           SUBROUTINE SMTESC
      C
      C         THIS SUBROUTINE ADJUSTS COSTS FOR 15 EQUIPMENT CATEGORIES
      C    BASED ON CE COST INDEX RATIOS. THE INDEX YEAR USED FOR EACH CAT-
      C    EGORY IS INPUT (ARRAY IRYP). THE ESCALATED COSTS ARE CONTAINED
      C    IN ARRAY RTOTAL. AN ADJUSTMENT IS ALSO MADE FOR COOLING POND
      C    LINER COST. THE BASE YEAR IS CURRENTLY 1981.
      C         THE USER MAY ALSO INCLUDE HIS OWN INDICES.
      C
      C
      C
      C
           CHARACTER*3 CEI,IFCLIS*30,SYSTEM*10
           DIMENSION CEBASE(6),XC(2,4),XCF(3),QUAN(4),AC(13)
           COMMON /COM01/ SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,
          &RICNTG,XC,XCF,RTI,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,IBYPAS,IRET
           COMMON /COM03/ EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
          & JMIN(4,10),JMAX(4,10),IFCLIS(15),IPT(9,30)
           COMMON /COM05/ PREC,NXOT,IENTRY,NOUT,NXX4,NXX5,AC,QUAN,ALPHA,
          & ACLNR,XX5
           COMMON /COM06/ IBYR,CEI(6 ),IRYP(6),RTOTAL(15),RSTOT,
          & RTOTD,RTOTI,PACLNR,IRYPLN,RTOTC,NCEI(15)
           COMMON /INDCOM/ XIND(6)
           DO 5 I=1,15
         5 RTOTAL(I)=0.0
      C
           IBYR=81
      C
      C    INPUT BASE YEAR INDICES
           IP=IBYR-69
           READ(15'IP,1000) CEBASE
      1000 FORMAT(6F5.0)
      C
      C    COMPUTE ESCALATED COSTS AND ROUND OFF RESULTS
      C    (SOME COSTS WILL BE EXTRANEOUS)
           DO 20 I=1,10
             IF(ISYS .EQ. 4 .AND. I .LT. 3) GO TO 20
             N=NCEI(I)
             FACTOR=XIND(N)/CEBASE(N)
             IF(I .NE. 7 .AND. I .NE. 10) GO TO 15
             RTOTAL(I)=TOTAL(6)*FACTOR
             CALL SMTRO(RTOTAL(I),100.)
             GO TO 20
        15   RTOTAL(I)=TOTAL(I)*FACTOR
             CALL SMTRO(RTOTAL(I),100.)
        20   CONTINUE
           RTOTAL(11)=TOTAL(7)*XIND(NCEI(11))/CEBASE(NCEI(11))
           RTOTAL(12)=TOTAL(1)*XIND(NCEI(12))/CEBASE(NCEI(12))
           CALL SMTRO(RTOTAL(11),100.)
           CALL SMTRO(RTOTAL(12),100.)
           RSTOT=0.0
      C
      C    CALCULATE SUBTOT FOR SYSTEM
           DO 25 I=1,5
        25   RSTOT=RSTOT+RTOTAL(I)
           IF(ISYS .EQ. 1 .OR. ISYS .EQ. 3) RSTOT=RSTOT+RTOTAL(6)
      IF(ISYS .EQ. 2) RSTOT=RSTOT+RTOTAL(7)
      IF(ISYS .EQ. 4) RSTOT=RSTOT+RTOTAL(10)
      IF(ISYS .EQ. 4) RSTOT=RSTOT+RTOTAL(12)
      IF((ISYS .EQ. 4 .OR. ISYS .EQ. 2) .AND. LIQUID .EQ. 1)
     & RSTOT=RSTOT+RTOTAL(11)
C
C     CALCULATE DIRECTS TOTAL
      RTOTD=RSTOT+RTOTAL(8)+RTOTAL(9)
C
C     CALCULATE INDIRECTS TOTAL
      RTOTAL(13)=RTOTD*.3125
      RTOTAL(14)=(RTOTD+RTOTAL(13))*RCAP*YCON*.325
      RTOTAL(15)=PICNTG*(RTOTD+RTOTAL(13)+RTOTAL(14))
      DO 30 I=13,15
   30 CALL SMTRO(RTOTAL(I),100.)
      RTOTI=RTOTAL(13)+RTOTAL(14)+RTOTAL(15)
C
C     CALCULATE CAPITAL COSTS
      RTOTC=RTOTI+RTOTD
C
C     CALCULATE LINER COST
      RACLNR=ACLNR*XIND(1)/CEPASE(1)
      IRYRLN=IRYR(1)
C
      RETURN
      END
**
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```
S*T*SMELTER(1).FLW(2)
      SUBROUTINE SMTFLW
C
C          THIS SUBROUTINE MAKES GAS FLOW CALCULATIONS AND
C      INITIALIZES EQUIPMENT ARRAYS
C
      DIMENSION ABRAT(4),FACT1(4),XC(2,4),XCF(3)
      CHARACTER SYSTEM*10
      CHARACTER*30 IFCLIS(15)
      COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,
     &RICNTG,XC,XCF,RTI,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,IBYPAS,IRET
      COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPHSO2,SO2AB,PPMSIN
     *                 ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPHH2O,PPHAIR,
     *                 PPHTOT,PPHABU,PPHABN
      COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
     *                  JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
      COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
     *                  ,TOTC
      DATA ABRAT/.6750,0.625,1.560,1.0/
      DATA FACT1/1.1,1.1,1.4,1.0/
      DO 100 I=1,300
      EQUIPS(I)=0.0
      NEQUIP(I)=0
      COST(I) = 0.0
      IF (I.GT.15) GO TO 100
      TOTAL(I) = 0.0
  100 CONTINUE
      DSO2=PSO2/100.0
      PPHSO2=SCFM*DSO2*60.0*64.0/386.7
      DH2O = H2OCON/100.0
      PPHH2O = SCFM * DH2O * 60.0 * 18.02 /386.7
      PPHAIR = SCFM * (1.0 - DSO2 -DH2O) * 60.0 * 28.9 /386.7
      PPHTOT = PPHSO2 + PPHH2O + PPHAIR
      ACFM = SCFM * (460.0 + DEGF)/530.0
      SO2AB = PPHSO2*EFF/100.
      PPHABU = SO2AB * ABRAT(ISYS)
      PPHABN = PPHABU * FACT1(ISYS) * 100./EFF
C
C     SO2 CONCENTRATIONS
C     SO2OUT,H2OOUT,AIROUT = PPH (#/HR)
      PPMSIN = DSO2*1000000.
      SO2OUT = PPHSO2 - SO2AB
      H2OOUT = PPHAIR*587./530.*.112
      AIROUT = SO2OUT+H2OOUT+PPHAIR+(PPHAIR+SO2OUT+H2OOUT)*.77
      PPMSOT=SO2OUT*386.7/64./60.*1000000./((SCFM-SO2AB*386.7/64.
     &/60.)*1.77)
      RETURN
      END
**
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```
SMT*SMELTER(1).INS(6)
      SUBROUTINE SMTINS
C
C          THIS SUBROUTINE PRINTS A FORMATED SUMMARY OF USER'S INPUT
C     DATA. A CE COST ESCALATION INDEX IS READ OFF DISC FOR EACH YEAR
C     FOR WHICH THE USER HAS NOT SUPPLIED AN INDEX (BEFORE 1981).
C
      CHARACTER*10 SYSTEM,CEI*3,RAW*15(6),OPEQP*3(4),YESNO*3(2)
      CHARACTER SOLSEL(6),RETSEL(3),X,B,DATE*8
      DIMENSION XC(2,4),SE(4),XCF(3),AC(13),QUAN(4)
      COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,RICNTG,
     &XC,XCF,RTI,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,IBYPAS,IRET
      COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPMSO2,SO2AB,PPMSIN
     *                ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPMH2O,PPMAIR,
     *                PPMTOT,PPMABU,PPMABN
      COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
     *                JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
      COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
     *                 ,TOTC
      COMMON /COM05/PREC,NXOT,IENTRY,NOUT,NXX4,NXX5,AC,QUAN,
     *          ALPHA,XX4,XX5
      COMMON /COM06/ IBYR,CEI(6),IRYR(6),RTOTAL(15),RSTOT,
     &        RTOTD,RTOTI,RACLNR,IRYRLN,RTOTC,NCEI(15)
      COMMON /COM07/SYSSAV,ISAV,I1
      COMMON /CITRAT/ SA,CIT,OIL,SAQ,CITQ,OILQ,SAC,CITC,OILC
      COMMON /HEAD/ IPAGE,DATE
      COMMON /INDCOM/ XIND(6)
      DATA RAW/'LIME           ','LIMESTONE      ',
     &         'MGO            ','CITRIC ACID    ',
     &         'SODA ASH       ','SULFURIC ACID  '/
      DATA X/'X'/,B/' '/,YESNO/'NO ','YES'/
      DATA SE/90.,92.,65.,95./
C
C     READ ESCALATION INDICES IF NOT INPUT
C
      DO 30 I=1,6
      IP=IRYR(I)-69
      IF(XIND(I) .EQ. 0.) READ(15'IP,1) (XIND(I),J=1,I)
    1 FORMAT(6F5.1)
   30 CONTINUE
      IF(IENTRY .EQ. 0 .AND. NOUT .EQ. 6) RETURN
      IPAGE = IPAGE + 1
      WRITE(NOUT,50) IPAGE,DATE
C
      WRITE(NOUT,100)
      WRITE(NOUT,200) SYSTEM,SCFM,INT(DEGF),PSO2,H2OCON
      WRITE(NOUT,300) INT(EFF),PLIFE
      IF(EFF .EQ. SE(ISYS)) WRITE(NOUT,350)
      WRITE(NOUT,400) NDAYS
C
C     YES OR NO ON OPTIONAL EQUIPMENT
C
      OPEQP(1)=YESNO(IBYPAS+1)
      OPEQP(2)=YESNO(IVENT+1)
      OPEQP(3)=YESNO(ISTACK)
      OPEQP(4)=YESNO(INT(PREC)+1)
      WRITE(NOUT,500) OPEQP
      IF(DEGF .GE. 400.) WRITE(NOUT,550)
C
C     PRINT SOLIDS DISPOSAL METHOD OR LIQUID SO2 OPTION
C
      IF(ISYS .EQ. 2 .OR. ISYS .EQ. 4) WRITE(NOUT,570) YESNO(LIQUID+1)
      IF(ISYS .EQ. 2 .OR. ISYS .EQ. 4) GO TO 15
      DO 10 I=1,6
      IF(ISOLID .EQ. I) SOLSEL(I)=X
   10 IF(ISOLID .NE. I) SOLSEL(I)=B
      WRITE(NOUT,580) SOLSEL
C
C     PRINT INSTALLATION FACTOR (RETROFIT) SELECTED
C
   15 DO 20 I=1,3
      IF(IRET .EQ. I) RETSEL(I)=X
      IF(IRET .NE. I) RETSEL(I)=B
   20 CONTINUE
      WRITE(NOUT,600) RETSEL
C
C
C     PRINT OUT RAW MATERIAL COSTS
C
      WRITE(NOUT,650)
      IF(ISYS .EQ. 1) WRITE(NOUT,750) RAW(1),XC(1,1)
      IF(ISYS .EQ. 2) WRITE(NOUT,750) RAW(3),XC(1,2)
      IF(ISYS .EQ. 3) WRITE(NOUT,750) RAW(2),XC(1,3),RAW(1),XC(2,3)
      IF(ISYS .EQ. 4) WRITE(NOUT,750) RAW(4),CIT,RAW(5),SA
      IF(LIQUID .EQ. 1) WRITE(NOUT,750) RAW(6),XC(2,ISYS)
      WRITE(NOUT,700) RCAP*100.,RTI*100.,RICNT6*100.,YCON
C
C     PRINT UTILITIES AND LABOR COSTS
C
      WRITE(NOUT,800) XCF(1),XCF(2)
      IF(ISYS .EQ. 2) WRITE(NOUT,850) OIL
      WRITE(NOUT,900) XCF(3)
C
C     PRINT ESCALATION YEARS AND INDICES
C
      WRITE(NOUT,1000) (IRYR(I),XIND(I),I=1,6)
C
      RETURN
C
   50 FORMAT(1H1,'PAGE ',I4,T67,A8)
  100 FORMAT(1H0,T33,'INPUT SUMMARY',/T32,15(1H-))
  200 FORMAT('0 SYSTEM NAME: ',A10,T28,'SCFM:',F8.0,1H@,I4,' DEG F',
     &        T55,F4.1,'% SO2',F5.1,'% MOISTURE')
  300 FORMAT(T28,'EFFICIENCY:',I3,'%',T54,'PLANT LIFE:',F5.1,' YEARS')
  350 FORMAT(1H+,T44,'(MAXIMUM)')
  400 FORMAT(T28,'NUMBER OF DAYS STORAGE OF FRESH ABSORBANT:',I3)
  500 FORMAT(1H0,T28,'OPTIONAL EQUIPMENT INCLUDED',
     &        /T32,'BYPASS TO STACK: ',A3,
     &        /T32,'VENTURI:         ',A3,
     &        /T32,'STACK:           ',A3,
     &        /T32,'PRECOOLER:       ',A3)
  550 FORMAT(1H+,T53,'(REQUIRED)')
  570 FORMAT(1H0,T28,'LIQUID SO2 INCLUDED: ',A3)
  580 FORMAT(1H0,T28,'SOLIDS DISPOSAL METHOD USED',
     &      /T31,'_ 1 - DIRECT TO POND',
     &      /1H+,T31,A1,
     &      /T31,'_ 2 - THICKENER/POND',
     &      /1H+,T31,A1,
     &      /T31,'_ 3 - THICKENER/VACUUM FILTER',
     &      /1H+,T31,A1,
     &      /T31,'_ 4 - THICKENER/CENTRIFUGE',
     &      /1H+,T31,A1
     &      /T31,'_ 5 - OXIDATION/THICKENER/CENTRIFUGE',
     &      /1H+,T31,A1,/T38,'(GYPSUM)',
     &      /T31,'_ 6 - OXIDATION/THICKENER/VACUUM FILTER',
     &      /1H+,T31,A1,/T38,'(GYPSUM)')
  600 FORMAT(1H0,T28,'INSTALLATION FACTOR',
     &      /T31,'_ 1 - EASY OR NEW INSTALLATION',
     &      /1H+,T31,A1,
     &      /T31,'_ 2 - MODERATELY DIFFICULT INSTALLATION',
     &      /1H+,T31,A1,
     &      /T31,'_ 3 - DIFFICULT INSTALLATION',
     &      /1H+,T31,A1)
  650 FORMAT(1H0,T14,'COST OPTIONS: RAW MATERIAL COSTS ($/TON)')
  700 FORMAT(1H0,T28,'CAPITAL COST:',F5.1,1H%,/
     &      T28,'TAXES & INSURANCE:',F5.1,1H%,/T28,
     &      'CONTINGENCY:',F5.1,1H%,
     &      /T28,'YEARS TO CONSTRUCT:',F4.1)
  750 FORMAT(2(T28,A15,1H:,F7.2,/))
  800 FORMAT(T28,'WATER ($/MGAL):',F5.2,/T28,'ELECTRICITY (MILLS/KWH):',
     &      F5.1)
  850 FORMAT(T28,'OIL ($/GAL):',F5.2)
  900 FORMAT(T28,'LABOR ($/MANHOUR):',F5.2)
 1000 FORMAT(1H0,T10,'CE PROCESS AREA',T45,'REF YEAR',T56,'INDEX',
     &      /T10,51(1H-),/T10,
     &      'PLANT COST(PC)',T48,I2,T56,F5.1,/T10,
     &      'EQUIPMENT, MACHINERY, & SUPPORTS(E*S)',T48,I2,T56,F5.1,/
     &  T10,'FABRICATED EQUIPMENT(FE)',T48,I2,T56,F5.1,/T10,
     &      'PROCESS MACHINERY(PM)',T48,I2,T56,F5.1,/T10,
     &      'CONSTRUCTION LABOR(CL)',T48,I2,T56,F5.1,/T10,
     &      'PUMPS & COMPRESSORS(PC)',T48,I2,T56,F5.1)
C
      END
**
```

```
SMT*SMELTER(1).LM1(3)
      SUBROUTINE SMTLM1
      CHARACTER SYSTEM*10
      CHARACTER*30 IFCLIS(15)
      DIMENSION XC(2,4),XCF(3)
      COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,
     &RICNTG,XC,XCF,RTI,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,IBYPAS,IPET
      COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPHSO2,SO2AB,PPMSIN
     *                  ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPHH2O,PPHAIR,
     *                  PPHTOT,PPHABU,PPHABN
      COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
     *                   JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
      COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
     *                     ,TOTC
C     LIME
C ****MATERIAL HANDLING****
C
C     STORAGE SILO
      EQUIPS(2)=PPHABN*24.0*NDAYS/2000.0
      NEQUIP(2)=(EQUIPS(2)/1272.)+1.0
      IF(NEQUIP(2) .LE. 2 ) NEQUIP(2)=2
      EQUIPS(2)=EQUIPS(2)/NEQUIP(2)
C
C     SCREW CONVEYOR ON STORAGE SILO
      EQUIPS(1)=PPHABN*4.0/2000.0/NEQUIP(2)
      NEQUIP(1)=NEQUIP(2)
C
C     PNEUMATIC CONVEYOR
      EQUIPS(3)=PPHABN*10./2000.
      NEQUIP(3)=1.
C
C     BAGHOUSE ON STORAGE SILO
      EQUIPS(4)=EQUIPS(3)*700./7.5
      NEQUIP(4)=1.
C
C     BUCKET ELEVATOR
      EQUIPS(7)=PPHABN*4./2000.
      NEQUIP(7)=2
C
C     DAY SILO
      EQUIPS(6)=EQUIPS(7)*24./4.
      NEQUIP(6)=2
C
C     ROTARY FEEDER
      EQUIPS(5)=1.0
      NEQUIP(5)=NEQUIP(2)+NEQUIP(6)
C
C     BAGHOUSE ON DAY SILO
      EQUIPS(164)=EQUIPS(7)*700./7.5
      NEQUIP(164)=1.
C
C     SCREW CONVEYOR ON DAY SILO
      EQUIPS(165)=PPHABN*1.3/2000.
      NEQUIP(165)=1.
C
C****FEED PREPARATION****
C     SLAKER
```

```
      EQUIPS(8)=EQUIPS(165)
      NEQUIP(8)=2
C
C     24 HOUR HOLD TANK AND AGITATOR
      EQUIPS(9)=PPHABN*24.*1.1/(.4*1.39*62.4)
      NEQUIP(9)=2
      CALL SMTTNK(EQUIPS(9),NEQUIP(9),EQUIPS(10),NEQUIP(10))
C
C     PUMP TO DILUTION TANK
      EQUIPS(11)=PPHABN/(.4*8.33*60.*1.39)
      NEQUIP(11)=2
C
C     12-HR DILUTION TANK AND AGITATOR
      EQUIPS(12)=PPHABN*12.*1.1/(.1*62.4*1.07)
      NEQUIP(12)=2
      CALL SMTTNK(EQUIPS(12),NEQUIP(12),EQUIPS(13),NEQUIP(13))
      NEQUIP(12)=2
      NEQUIP(13)=6
C
C     ABSORBENT MAKE-UP PUMP
      EQUIPS(166)=PPHABN/(.1*8.33*60.*1.07)
      NEQUIP(166)=2.
C
      RETURN
      END
**
```

```
SMT*SMELTER(1).LM2(3)
      SUBROUTINE SMTLM2
      CHARACTER SYSTEM*10
      CHARACTER*30 IFCLIS(15)
      DIMENSION XC(2,4),XCF(3)
      COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,
     &RICNTG,XC,XCF,RTI,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,IBYPAS,IRET
      COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPHSO2,SO2AB,PPMSIN
     *                ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPHH2O,PPHAIR,
     *                PPHTOT,PPHABU,PPHABN
      COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
     *                 JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
      COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
     *                  ,TOTC
C     LIME
C ****SOLIDS DISPOSAL****
C
C     SIZING
      CASO3 = PPHABN/1.1*120./56.*.9
      CAOUR=PPHABN/1.1*0.2
      PPHWN=PPHABN*.9/.1
      PPHS = PPHWN + CASO3 + CAOUR
      PPHSLD=CASO3+CAOUR
      PPHPND=PPHSLD/.10
C
      IF(ISOLID .EQ. 1) GO TO 108
      IF(ISOLID .GE. 5) GO TO 100
      PPHT=PPHS
C
C     THICKENER HOLD TANK
      EQUIPS(174)=PPHT*8.*1.1/(62.4*1.10)
      NEQUIP(174)=1
      CALL SMTTNK(EQUIPS(174),NEQUIP(174),EQUIPS(175),NEQUIP(175))
      GO TO 101
C
C     PH TANK AND AGITATOR
  100 EQUIPS(35)= PPHS *12.*1.1/(62.4 * 1.10)
      NEQUIP(35)= 1
      CALL SMTTNK(EQUIPS(35),NEQUIP(35),EQUIPS(36),NEQUIP(36))
C
C     PUMP TO OXIDATION TANK
      EQUIPS(176)=PPHS/(8.33*60.*1.10)
      NEQUIP(176)=2
C
C     OXIDATION TANK
      NEQUIP(37) = 1
      PPHT = CASO3 * 16./120. + PPHS
      PPHSLD=CASO3*16./120.+PPHSLD
      EQUIPS(37) = PPHT * 6.*1.1/(62.4 * 1.10)
      CALL SMTTNK(EQUIPS(37),NEQUIP(37),EDUMMY,NDUMMY)
C
C     COMPRESSOR
      EQUIPS(177)=CASO3*0.9/120./60.*386.7/.21*14.7/114.7*560./530.
      IF(EQUIPS(177) .GT. 522.) GO TO 10
      NEQUIP(177)=1
      GO TO 40
   10 IF(EQUIPS(177) .GT. 1044.) GO TO 20
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      NEQUIP(177)=2
      EQUIPS(177)=EQUIPS(177)/2.
      GO TO 40
   20 IF(EQUIPS(177) .GT. 1250.) GO TO 30
      NEQUIP(177)=3
      EQUIPS(177)=EQUIPS(177)/3.
      GO TO 40
   30 NEQUIP(177)=1
   40 CONTINUE
C
C     PUMP TO THICKENER
  101 NEQUIP(38)=2
      EQUIPS(38)=PPHT/(8.33 * 60. * 1.10)
C
C     THICKENER
      NEQUIP(39)=1
      EQUIPS(39) = 2.*SQRT(PPHSLD*24./2000.*39./3.14159)
      PPHSLD=PPHSLD*16./120.*CASO3
C
C     PUMP FROM THICKENER
      EQUIPS(178)=PPHSLD/(.2*8.33*60.*1.125)
      NEQUIP(178)=2
C
      PPHPND=PPHSLD/.20
      PPHTOT=PPHSLD/.6
      IF(ISOLID .GE. 5) PPHTOT=PPHSLD/.8
      IF(ISOLID .EQ. 2) GO TO 107
C
C     SOLIDS HOLD TANK AND AGITATORS
      NEQUIP(40) = 1
      EQUIPS(40) = PPHSLD*2.0*1.17(0.2*62.4*1.125)
      CALL SMTTNK(EQUIPS(40),NEQUIP(40),EQUIPS(41),NEQUIP(41))
C
C     PUMP FROM SOLIDS HOLD TANK
      EQUIPS(179)=EQUIPS(178)
      NEQUIP(179)=2
      IF(ISOLID .EQ. 3 .OR. ISOLID .EQ. 6) GO TO 104
C
C     CENTRIFUGE
      EQUIPS(42)=PPHSLD
      NEQUIP(42) = EQUIPS(42) / 11260. + 2.
      EQUIPS(42)=EQUIPS(42)/(NEQUIP(42)-1)
      IF(NEQUIP(42) .LT. 5) GO TO 103
      NEQUIP(42)=NEQUIP(42)+1
C
C     PUMP TO LIQUID HOLD TANK
  103 NEQUIP(46)=NEQUIP(42)
      EQUIPS(46)=(PPHSLD/.2-PPHTOT)/NEQUIP(42)/(8.33*60.*1.47)
      IF(ISOLID .EQ. 5) EQUIPS(46)=EQUIPS(46)*1.47/1.81
C
C     SCREW CONVEYOR
      NEQUIP(43)=2
      EQUIPS(43)=PPHTOT/2000.
      GO TO 105
C
C     VACUUM FILTER
  104 EQUIPS(180)=PPHSLD/120.*1.2
```

```
      NEQUIP(180)=EQUIPS(180)/817.+1.
      EQUIPS(180)=EQUIPS(180)/NEQUIP(180)
      IF(NEQUIP(180) .LT. 2) NEQUIP(180)=2
C
C     BELT CONVEYOR
      EQUIPS(181)=PPHTOT
      NEQUIP(181)=1
C
C     DUMP TRUCK
  105 NEQUIP(47)=3
      IF(EQUIPS(43) .GT. 66.) GO TO 106
      EQUIPS(47)=1.
      GO TO 107
  106 EQUIPS(47)=85000./60000.
C
C     LIQUID HOLD TANK
  107 NEQUIP(44)=1
      EQUIPS(44)=(PPHT-PPHTOT)*1.1*3./62.4
      CALL SMTTNK(EQUIPS(44),NEQUIP(44),EDUMMY,NDUMMY)
C
C     PUMP FROM LIQUID HOLD TANK
      EQUIPS(183)=.99*(PPHT-PPHTOT)/(8.33*60.)
      NEQUIP(183)=2
      IF(ISOLID .GE. 3) GO TO 999
C
C     PUMP TO AND FROM POND
  108 EQUIPS(184)=(PPHPND-PPHSLD/.6)/(8.33*60.)
      NEQUIP(184)=3
C
C     PIPING TO AND FROM POND
      IF (ISOLID .EQ. 1) EQUIFS(48)=PPHSLD
      IF (ISOLID .EQ. 1) NEQUIP(48)=2
C
C     PIPING FROM THICKENER TO AND FROM POND
      IF (ISOLID .EQ. 2) EQUIPS(49)=PPHSLD
      IF (ISOLID .EQ. 2) NEQUIP(49)=3
C
  999 RETURN
      END
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```
SPT*SMELTER(1).LS1(1)
                SUBROUTINE SMTLS1
                CHARACTER SYSTEM*10
                CHARACTER*30 IFCLIS(15)
                DIMENSION XC(2,4),XCF(3)
                COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,
               &RICNTG,XC,XCF,RTI,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,IBYPAS,IPET
                COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPHSO2,SO2AB,PPMSIN
                *               ,PPMSOT,SO2OUT,H2OCON,PH20,DH20,PPHH20,PPHAIR,
                *               PPHTOT,PPHABU,PPHABN
                COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
                *                JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
                COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
                *                 ,TOTC
          C     LIMESTONE
          C ****MATERIALS HANDLING****
          C
          C     IN GROUND HOPPER
                NEQUIP(109)= 1
                EQUIPS(109)=1
          C
          C     CONVEYOR TO STORAGE-SLOPED
                EQUIPS(110)=PPHABN*10./2000.
                NEQUIP(110)=1
                TT=PPHABN*NDAYS*24./2000.
                IF(TT .LE. 5800.)GO TO 99
          C
          C     CONVEYOR TO STORAGE-HORIZONTAL
                EQUIPS(111)=(TT-5800.)/98.
                NEQUIP(111)=1
          C
          C     FRONT END LOADER
             99 T = PPHABN * 3. * 24. /(2000. * 8.)
                IF( T .GE. 84.5) GO TO 100
                EQUIPS(114)=1.
                NEQUIP(114)=2
                GO TO 1000
            100 IF(T .GE. 203.1) GO TO 101
                EQUIPS(114)=162000./76500.
                NEQUIP(114)=2
                GO TO 1000
            101 IF(T .GE. 406.2) GO TO 102
                EQUIPS(114)=162000./76500.
                NEQUIP(114)=3
                GO TO 1000
            102 IF(T .GE. 626.5) GO TO 103
                EQUIPS(114)=332500./76500.
                NEQUIP(114)=3
                GO TO 1000
            103 EQUIPS(114)=653000./76500.
                NEQUIP(114)=3
           1000 CONTINUE
          C
          C     CONVEYOR HOPPER
                EQUIPS(167)=1
                NEQUIP(167)=2
          C
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C     CONVEYOR TO 3-DAY SILO
      NEQUIP(112)=1
      EQUIPS(112)=PPHABN*4./2000.
C
C     3-DAY SILO
      EQUIPS(115)=PPHABN*24.*3./2000.
      NEQUIP(115)=EQUIPS(115)/1430.+1.
      EQUIPS(115)=EQUIPS(115)/NEQUIP(115)
C
C     BAGHOUSE ON 3 DAY SILO
      EQUIPS(168)=EQUIPS(112)*700./7.5
      NEQUIP(168)=NEQUIP(115)
C
C     STONE COLUMN
      NEQUIP(113)=1
      EQUIPS(113)=NEQUIP(115)
C
C     ROTARY FEEDERS
      NEQUIP(116)=2*NEQUIP(115)
      EQUIPS(116)=1.
C
C     MAGNETIC DEVICE
      NEQUIP(117)=2
      EQUIPS(117)=1.
C
C     BELT CONVEYOR
      NEQUIP(118)=2
      EQUIPS(118)=PPHABN*2./2000.
C
C     BUCKET ELEVATOR
      NEQUIP(119)=2
      EQUIPS(119)=EQUIPS(118)
C
C     BAGHOUSE ON 24-HOUR SILO
      NEQUIP(120)=2
      EQUIPS(120)=EQUIPS(118)*700./7.5
C
C
C     DAY SILO
      EQUIPS(121)=PPHABN*24./2000.
      NEQUIP(121)=EQUIPS(121)/1430.+1.
      EQUIPS(121)=EQUIPS(121)/NEQUIP(121)
      IF(NEQUIP(121) .LT. 2) NEQUIP(121)=2
C
C     WEIGH FEEDERS
      NEQUIP(123)=NEQUIP(121)
      EQUIPS(123)=1.
C
C ****FEED PREPARATION****
C
C     BALL MILL
      EQUIPS(124)=PPHABN*1.2/2000.
      NEQUIP(124)=EQUIPS(124)/50.+1
      IF(NEQUIP(124) .LT. 2) NEQUIP(124)=2
      EQUIPS(124)=EQUIPS(124)/NEQUIP(124)
C
C     CLASSIFIER
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              NEQUIP(125)=2
              EQUIPS(125)=EQUIPS(124)
      C
      C       24-HR HOLD TANK AND AGITATORS
              NEQUIP(126)=2
              EQUIPS(126)=PPHABN*24.*1.1/(0.4* 62.4 * 1.35)
              CALL SMTTNK(EQUIPS(126),NEQUIP(126),EQUIPS(127),NEQUIP(127))
      C
      C       PUMP TO DILUTION TANK
              NEQUIP(128)=2
              EQUIPS(128)=PPHABN/(0.4*8.33*60.*1.35)
      C
      C       12-HR DILUTION TANK AND AGITATOR
              EQUIPS(129)=PPHABN*12.*1.1/(.1*62.4*1.065)
              NEQUIP(129)=2
              CALL SMTTNK(EQUIPS(129),NEQUIP(129),EQUIPS(130),NEQUIP(130))
              NEQUIP(129)=2
              NEQUIP(130)=6
      C
      C       ABSORBENT MAKE-UP PUMP
              EQUIPS(173)=PPHABN/(.1*8.33*60.*1.065)
              NEQUIP(173)=2
      C
              RETURN
              END
**
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```
SMT*SMELTER(1).LS2(4)
      SUBROUTINE SMTLS2
      CHARACTER SYSTEM*10
      CHARACTER*30 IFCLIS(15)
      DIMENSION XC(2,4),XCF(3)
      COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,
     &RICNTG,XC,XCF,RTI,RCAP,PLIFE,NDAY,ISOLID,YCON,IVENT,IBYPAS,IRET
      COMMON /COM02/ACFP,SCFM,DEGF,PSO2,DSO2,PPHSO2,SO2AB,PPMSIN
     *                   ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPHH2O,PPHAIR,
     *                   PPHTOT,PPHABU,PPHABN
      COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
     *                   JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
      COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
     *                    ,TOTC
C     LIMESTONE
C ****SOLIDS DISPOSAL****
C
C     SIZING
      CASO3 = PPHABN/1.4*120./100.*.85
      CACO3=PPHABN/1.4*.55
      PPHWN =PPHABN*.9/.1
      PPHS = PPHWN + CASO3 + CACO3
      PPHSLD=CASO3+CACO3
      PPHPND=PPHSLD/.10
C
      IF(ISOLID .EQ. 1) GO TO 198
      IF(ISOLID .GE. 5) GO TO 100
      PPHT=PPHS
C
C     THICKENER HOLD TANK
      EQUIPS(174)=PPHT*8.*1.1/(62.4*1.05)
      NEQUIP(174)=1
      CALL SMTTNK(EQUIPS(174),NEQUIP(174),EQUIPS(175),NEQUIP(175))
      GO TO 101
C
C     PH TANK AND AGITATOR
  100 EQUIPS(35)= PPHS *12.*1.1/(62.4 * 1.05)
      NEQUIP(35)= 1
      CALL SMTTNK(EQUIPS(35),NEQUIP(35 ),EQUIPS(36),NEQUIP(36 ))
C
C     PUMP TO OXIDATION TANK
      EQUIPS(176)=PPHS/(8.33*60.*1.05)
      NEQUIP(176)=2
C
C     OXIDATION TANK
      PPHT = CASO3 * 16./120. + PPHS
      PPHSLD=CASO3*16./120.+PPHSLD
      NEQUIP(37) = 1
      EQUIPS(37) = PPHT * 6.*1.1/( 62.4 * 1.05)
      CALL SMTTNK(EQUIPS(37),NEQUIP(37),EDUMMY,NDUMMY)
C
C     COMPRESSOR
      EQUIPS(177)=CASO3*.9/120./60.*386.7/.21*14.7/114.7*560./530.
      IF(EQUIPS(177) .GT. 522.) GO TO 10
      NEQUIP(177)=1
      GO TO 40
   10 IF(EQUIPS(177) .GT. 1044.) GO TO 20
```

```
      NEQUIP(177)=2
      EQUIPS(177)=EQUIPS(177)/2.
      GO TO 40
   20 IF(EQUIPS(177) .GT. 1250.) GO TO 30
      NEQUIP(177)=3
      EQUIPS(177)=EQUIPS(177)/3.
      GO TO 40
   30 NEQUIP(177)=1
   40 CONTINUE
C
C     PUMP TO THICKENER
  101 NEQUIP(38)=2.
      EQUIPS(38)=PPHT/(60. * 8.33 * 1.05)
C
C     THICKENER
      NEQUIP(39)=1
      EQUIPS(39) = 2*SQRT(PPHSLD*24./2000.*26./3.14159)
      PPHSLD=PPHSLD+16./120.*CASO3
C
C     PUMP FROM THICKENER
      EQUIPS(178)=PPHSLD/(.2*8.33*60.*1.09)
      NEQUIP(178)=2
C
      PPHPAD=PPHSLD/.2
      PPHTOT=PPHSLD/.6
      IF(ISOLID .GE. 5) PPHTOT=PPHSLD/.8
      IF(ISOLID .EQ. 2) GO TO 107
C
C     SOLIDS HOLD TANK AND AGITATOR
      NEQUIP(40) = 1
      EQUIPS(40) = PPHSLD*2.0*1.1/(0.2*62.4 *1.09)
      CALL SMTTNK(EQUIPS(40),NEQUIP(40),EQUIPS(41),NEQUIP(41))
C
C     PUMP FROM SOLIDS HOLD TANK
      EQUIPS(179)=EQUIPS(178)
      NEQUIP(179)=2
      IF(ISOLID .EQ. 3 .OR. ISOLID .EQ. 6) GO TO 104
C
C     CENTRIFUGE
      EQUIPS(42)=PPHSLD
      NEQUIP(42)=EQUIPS(42)/11260.+2
      EQUIPS(42)=EQUIPS(42)/(NEQUIP(42)-1)
      IF(NEQUIP(42) .GE. 5) GO TO 102
      GO TO 103
  102 NEQUIP(42)=NEQUIP(42)+1
C
C     PUMP TO LIQUID HOLD TANK
  103 NEQUIP(46)=NEQUIP(42)
      EQUIPS(46)=(PPHSLD/.2-PPHTOT)/NEQUIP(42)/(8.33*60.*1.38)
      IF(ISOLID .EQ. 5) EQUIPS(46)=EQUIPS(46)*1.88/1.61
C
C     SCREW CONVEYOR
      NEQUIP(43)=2
      EQUIPS(43)=PPHTOT/2000.
      GO TO 105
C
C     VACUUM FILTER
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  104 EQUIPS(180)=PPHSLD/120.*1.2
      NEQUIP(180)=EQUIPS(180)/817.+1
      EQUIPS(180)=EQUIPS(180)/NEQUIP(180)
      IF(NEQUIP(180) .LT. 2) NEQUIP(180)=2
C
C     BELT CONVEYOR
      EQUIPS(181)=PPHTOT
      NEQUIP(181)=1
C
C     DUMP TRUCK
  105 NEQUIP(47)=3
      IF(EQUIPS(43) .GT. 66.) GO TO 106
      EQUIPS(47)=1.0
      GO TO 107
  106 EQUIPS(47)=85000./60000.
C
C     LIQUID HOLD TANK
  107 NEQUIP(44)=1
      EQUIPS(44)=(PPHT-PPHTOT)*1.1*3./62.4
      CALL SMTTNK(EQUIPS(44),NEQUIP(44),EDUMMY,NDUMMY)
C
C     PUMP FROM LIQUID HOLD TANK
      EQUIPS(183)=.99*(PPHT-PPHTOT)/(8.33*60.)
      NEQUIP(183)=2
      IF(ISOLID .GE. 3) GO TO 999
C
C     PUMP TO AND FROM POND
  108 EQUIPS(184)=(PPHPND-PPHSLD/.6)/(8.33*60.)
      NEQUIP(184)=3
C
C     PIPING TO AND FROM POND
      IF (ISOLID .EQ. 1) EQUIPS(48)=PPHSLD
      IF (ISOLID .EQ. 1) NEQUIP(48)=3
C
C     PIPING FROM THICKENER TO AND FROM POND
      IF (ISOLID .EQ. 2) EQUIPS(49)=PPHSLD
      IF (ISOLID .EQ. 2) NEQUIP(49)=3
C
  999 RETURN
      END
**
```

```
SMT*SMELTER(1).M61(4)
                SUBROUTINE SMTM61
                CHARACTER SYSTEM*10
                CHARACTER*30 IFCLIS(15)
                DIMENSION XC(2,4),XCF(3)
                COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,
               &RICNTG,XC,XCF,RT1,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,IBYPAS,IRET
                COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPHSO2,SO2AB,PPMSIN
                *                 ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPHH2O,PPHAIR,
                *                 PPHTOT,PPHABU,PPHABN
                COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
                *                  JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
                COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
                *                  ,TOTC
          C
          C**** MGO REGENERATION ****
          C
          C     SIZING
                RMGSO3=PPHABN/1.1*104./40.*.92
                REMGO=PPHABN/1.1*.18
                REH2O=PPHABN*.9/.1
                RETOT=RMGSO3+REMGO+REH2O
          C
          C     LIQUID CYCLONE
                EQUIPS(70)=RETOT/(1.15*8.33*60.)
                NEQUIP(70)=1
          C
          C     STREAMS FROM LIQUID CYCLONE
                CLW=(RMGSO3+REMGO-(REH2O*0.3/0.7))/(-0.353)
                CLOTOT=CLW*1.03867
                CLUH2O=REH2O-CLW
                CLUSLD=RMGSO3+REMGO-(CLW*0.03867)
                CLUTOT=CLUH2O+CLUSLD
          C
          C     SURGE TANK AND AGITATOR
                EQUIPS(71)=((CLUTOT*4.*1.1/(62.4*1.23))
                NEQUIP(71)=1
                CALL SMTTNK(EQUIPS(71),NEQUIP(71),EQUIPS(72),NEQUIP(72))
          C
          C     CENTRIFUGE
                NEQUIP(73)=(CLUSLD /11260.0)+2.0
                EQUIPS(73)=CLUSLD /(NEQUIP(73)-1)
                IF(NEQUIP(73) .LE. 2) NEQUIP(73)=2
          C
          C     CENTRIFUGE FLOWS
                CTW=(CLUSLD-(CLUH2O*.6/.4))/(-1.495)
                CTOTOT=CTW*1.005
                CTUH2O=CLUH2O-CTW
                CTUSLD=CLUSLD-(CTW*0.005)
                CTUTOT=CTUH2O+CTUSLD
          C
          C     LIQUID OVERFLOW HOLD TANK
                EQUIPS(74)=(CLOTOT+CTOTOT)*24.*1.1/(62.4*1.0134)
                NEQUIP(74)=1
                CALL SMTTNK(EQUIPS(74),NEQUIP(74),EQUIPS(75),NEQUIP(75))
          C
          C     SCREW CONVEYOR FROM CENTRIFUGE
```

```
      EQUIPS(76)=CTUTOT/(NEQUIP(73)-1)/2000.
      NEQUIP(76)=NEQUIP(73)
C
C     ROTARY DRYER
      EQUIPS(77)=CTUTOT
      NEQUIP(77)=1
C
C     BELT CONVEYOR
      EQUIPS(81)=CTUSLD
      NEQUIP(81)=1
C
C     BUCKET ELEVATOR
      EQUIPS(78)=CTUSLD/2000.
      NEQUIP(78)=1
C
C     MGSO4 STORAGE SILO
      EQUIPS(79)=EQUIPS(78)*4.
      NEQUIP(79)=1
C
C     ROTARY FEEDER
      EQUIPS(86)=1.0
      NEQUIP(86)=1
C
C     WEIGH FEEDER
      EQUIPS(80)=1.
      NEQUIP(80)=1
C
C     CYCLONE SEPARATOR (ROTARY DRYER)
      CYAIR1=CTUH2O*386.7/18.*740./530./60.
      CYAIR2=CTUH2O*386.7/18./.36*740./530./60.*16.3/15.3
      EQUIPS(82)=CYAIR1+CYAIR2
      NEQUIP(82)=1
C
C     DUCTING FROM ROTARY DRYER - INSULATED
      DUCTD0=2.*SQRT(EQUIPS(82)/3500./3.14159)
      DUCTL0=50.
      EQUIPS(190)=DUCTD0*DUCTL0*3.14159*16.
      NEQUIP(190)=1
C
C     BAGHOUSE ON CYCLONE SEPARATOR
      EQUIPS(83)=EQUIPS(82)
      NEQUIP(83)=1
C
C     DUCTING FROM CYCLONE SEPARATOR TO BAGHOUSE - INSULATED
      DUCTD1=2.*SQRT(EQUIPS(82)/3500./3.14159)
      DUCTL1=35.
      EQUIPS(191)=DUCTD1*DUCTL1*3.14159*16.
      NEQUIP(191)=1
C
C     CALCINER
      EQUIPS(85)=CTUSLD
      NEQUIP(85)=1
C
C     BLOWER
      EQUIPS(87)=EQUIPS(85)/4000.*8.1*15.3*386.7/28.9*560./530.
      NEQUIP(87)=1
C
```

```
C     AIR/AIR HEAT EXCHANGER
      EQUIPS(88)=(CTUSLD/3.*386.7/60./105.6*CTUSLD*386.7/60./105.6
     &  )*1460./530.+EQUIPS(87)*1460./560.*16.3/15.3
      NEQUIP(88)=1
C
C     CYCLONE SEPARATOR (CALCINER)
      EQUIPS(90)=EQUIPS(88)
      NEQUIP(90)=1
C
C     DUCTING FROM CALCINER - REFRACTORY LINED
      DUCTD2=2.*SQRT(EQUIPS(88)/3500./3.14159)
      DUCTL2=60.
      EQUIPS(194)=DUCTD2*DUCTL2*3.14159
      NEQUIP(194)=1
C
C     WASTE HEAT BOILER
      EQUIPS(89)=(EQUIPS(87)*16.3/15.3*1460./560.)+(CTUSLD/3.*.05
     &*386.7/105.6/60.+CTUSLD*64./105.6*386.7/64./60.)*1460./530.
      NEQUIP(89)=1
C
C     DUCTING TO WASTE HEAT BOILER - REFRACTORY LINED
      DUCTD3=2.*SQRT(EQUIPS(89)/3500./3.14159)
      DUCTL3=100.
      EQUIPS(195)=DUCTD3*DUCTL3*3.14159
      NEQUIP(195)=1
C
C     OIL STORAGE TANK
      GPHCL1=(CTUH20/18.*28.9/.38)*(1200-100)*.25*1.1/144000.
      GPHOL2=(EQUIPS(85)*60.0/4000.0)
      EQUIPS(92)=(GPHOL1+GPHOL2)*720.0/7.48
      NEQUIP(92)=1
      CALL SMTTNK (EQUIPS(92),NEQUIP(92),EDUMMY,NDUMMY)
C
C     OIL HEATER
      EQUIPS(93)=EDUMMY
      NEQUIP(93)=NEQUIP(92)
C
C     OIL PUMP TO ROTARY DRYER
      EQUIPS(94)=GPHOL1/60.
      NEQUIP(94)=2
C
C     OIL PUMP TO CALCINER
      EQUIPS(197)=GPHOL2/60.
      NEQUIP(197)=2
C
C     DUCTING TO CALCINER - INSULATED
      DUCTD4=2.*SQRT(EQUIPS(88)/3500./3.14159)
      DUCTL4=50.
      EQUIPS(95)=DUCTD4*DUCTL4*3.14159*16.
      NEQUIP(95)=1
C
C**** MATERIALS HANDLING ****
C
C     BUCKET ELEVATOR
      EQUIPS(50)=2./3.*EQUIPS(78)*40./105.6
      NEQUIP(50)=2
C
```

```
C     CALCINER HOPPER
      EQUIPS(51)=EQUIPS(50)*2000.*4./40.
      NEQUIP(51)=1
C
C     PNEUMATIC CONVEYOR
      EQUIPS(52)=EQUIPS(50)/2.
      NEQUIP(52)=1
C
C     REGENERATED MGO SILO
      EQUIPS(91)=3./2.*EQUIPS(50)*72.
      NEQUIP(91)=1
C
C     BAGHOUSE ON REGEN. SILO
      EQUIPS(186)=(EQUIPS(50)+EQUIPS(52))*700./7.5
      NEQUIP(186)=1
C
C     WEIGH FEEDER
      EQUIPS(53)=1.
      NEQUIP(53)=2
C
C     BUCKET ELEVATOR
      EQUIPS(54)=EQUIPS(50)+EQUIPS(52)
      NEQUIP(54)=1
C
C     PNEUMATIC CONVEYOR
      EQUIPS(57)=PPHABN/2000.*.05*3.
      NEQUIP(57)=2
C
C     VIRGIN MGO SILO
      EQUIPS(55)=(PPHABN/2000.*.05)*NDAYS*24.
      NEQUIP(55)=1
C
C     BAGHOUSE ON VIRGIN AND DAY SILO
      EQUIPS(187)=EQUIPS(57)*700./7.5
      NEQUIP(187)=1
C
C     DAY SILO
      EQUIPS(56)=EQUIPS(55)/NDAYS
      NEQUIP(56)=1
C
C     WEIGH FEEDERS
      EQUIPS(189)= 1.
      NEQUIP(189)=1
C
C     DUCTING FROM DAY SILO TO BAGHOUSE
      DUCTD5=2.*SQRT(EQUIPS(57)*700./7.5/3500./3.14159)
      DUCTL5=75.
      EQUIPS(193)=DUCTD5*DUCTL5*3.14159*16.
      NEQUIP(193)=1
C
C     ROTARY FEEDER
      EQUIPS(59)=1.0
      NEQUIP(59)=3
C
C**** FEED PREPARATION ****
C
C     SLURRY TANK AND AGITATOR
```

```
      EQUIPS(60)=PPHABN*1.1*24./(0.4*62.4*1.24)
      NEQUIP(60)=1
      CALL SMTTNK(EQUIPS(60),NEQUIP(60),EQUIPS(61),NEQUIP(61))
C
C     SLURRY HEATER
      EQUIPS(62)=EQUIPS(61)
      NEQUIP(62)=1
C
C     12-HR DILUTION TANK AND AGITATOR
      EQUIPS(63)=((CLOTOT-CLW+CTOTOT-CTW+10.*PPHABN)*12.*1.1/
     $(62.4*1.08)
      NEQUIP(63)=1
      NEQUIP(63)=1
      CALL SMTTNK(EQUIPS(63),NEQUIP(63),EQUIPS(64),NEQUIP(64))
C
C     PUMP FROM SLURRY TANK TO DILUTION TANK
      EQUIPS(65)=PPHABN/(.4*8.33*60.*1.24)
      NEQUIP(65)=2
C
C     ABSORBENT MAKE-UP PUMP
      EQUIPS(198)=PPHABN/(.1*8.33*60.*1.08)
      NEQUIP(198)=2
C
C     PUMP FROM LIQUID OVERFLOW HOLD TANK
      EQUIPS(188)=(CLOTOT+CTOTOT)/(8.33*60*1.0134)
      NEQUIP(188)=1
C
C
C**** LIQUID SO2 ****
C
      IF (LIQUID.EQ.0) GO TO 9999
C
C     SPRAY CHAMBER
      EQUIPS(96)=EQUIPS(89)*1060./1460.-(CTUSLD/3.*.05*386.7/105.6/60.
     $)*1060./530.
      NEQUIP(96)=1
C
C     PUMP TO SPRAY CHAMBER
      EQUIPS(196)=PPHSO2*3.79/(8.33*60.)
      NEQUIP(196)=2
C
C     PUMP TO 98% ACID STORAGE TANK
      PPHWAT=SO2AB/64.*.0842*18.
      EQUIPS(212)=(PPHWAT*.7/.28)*10./(8.33*60.*1.836)
      NEQUIP(212)=2
C
C     98% ACID STORAGE TANK
      EQUIPS(213)=PPHWAT*.7/.28*24.*30./(62.4*1.836)
      NEQUIP(213)=1
      CALL SMTTNK (EQUIPS(213),NEQUIP(213),EDUMMY,NDUMMY)
C
C     PUMP FROM 98% ACID STORAGE TANK
      EQUIPS(214)=EQUIPS(212)/10.
      NEQUIP(214)=2
C
C     DRYING COLUMN
      EQUIPS(97) = EQUIPS(96)*587.0/1060.
      NEQUIP(97) = 1
C
C     PUMPS AT DRYING COLUMN
      EQUIPS(96) = PPHSO2 * 3.2/500.
      NEQUIP(98) = 4
C
C     ACID COOLER
      EQUIPS(99) = PPHSO2*94.0/5487.0
      NEQUIP(99) = 1
C
C     90% ACID HOLD TANK
      EQUIPS(215)=EQUIPS(212)*.98/.7*60.*24.*1.836/(7.48*1.61*10.)
      NEQUIP(215)=1
      CALL SMTINK (EQUIPS(215),NEQUIP(215),EDUMMY,NDUMMY)
C
C     PUMP FROM 90% ACID HOLD TANK
      EQUIPS(216)=EQUIPS(212)*.98/.7*1.836/1.61
      NEQUIP(216)=2
C
C     90% ACID STORAGE TANK
      EQUIPS(217)=EQUIPS(215)*30.
      NEQUIP(217)=1
      CALL SMTINK (EQUIPS(217),NEQUIP(217),EDUMMY,NDUMMY)
C
C     BLOWER TO DRYING COLUMN
      EQUIPS(100) = EQUIPS(97)
      NEQUIP(100) = 1
C
C     COMPRESSOR
      EQUIPS(101) = EQUIPS(100)*520./587.
      NEQUIP(101) = 1
C
C     STORAGE RECEIVER/TANK
      EQUIPS(102) = PPHSO2*4.0*24./(62.4*1.36)
      NEQUIP(102) = 1
C
C     PUMP TO STORAGE
      EQUIPS(103) = PPHSO2/(6.33*1.43*60.0)
      NEQUIP(103) = 2
C
C     DUCTING TO LIQUID SO2 PLANT (W/ HAIRPIN COOLER)
      DUCTD6=2.*SQRT(EQUIPS(96)/3500./3.14159)
      DUCTL6=400.
      EQUIPS(104)=DUCTD6*DUCTL6*3.14159*16.
      NEQUIP(104)=1
 9999 RETURN
      END
**
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```
SPT*SMELTER(1).OT1(10)
      SUBROUTINE SMTOT1
C
C          THIS SUBROUTINE PRINTS OUT A SUMMARY OF CAPITAL COSTS.
C      COSTS ARE PRINTED IN 1981 DOLLARS IN ADDITION TO COSTS BASED
C      ON REFERENCE YEARS SUPPLIED BY THE USER.
C
C
      CHARACTER*30 ICLIST(3)
      CHARACTER SYSTEM*10
      CHARACTER*30 IFCLIS(15)
      CHARACTER*3 CEI,DATE*6
      DIMENSION AC(13),QUAN(4),XC(2,4),XCF(3)
      COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,
     &RICNTG,XC,XCF,RTI,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,
     &IBYPAS,IRET
      COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPMSO2,SO2AB,PPMSIN
     *                    ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPMH2O,PPMAIR,
     *                    PPMTOT,PPMABU,PPMABN
      COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
     *                    JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
      COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
     *                    ,TOTC
      COMMON /COM05/PREC,NXOT,IENTRY,NOUT,NXX4,NXX5,AC,QUAN,
     *          ALPHA,ACLNR,XX5
      COMMON /COM06/ IBYR,CEI(6),IRYR(6),RTOTAL(15),RSTOT,
     &              RTOTD,RTOTI,RACLNR,IRYRLN,RTOTC,NCEI(15)
      COMMON /HEAD/ IPAGE,DATE
      DATA ICLIST/'INDIRECTS (31.25% OF DIRECT)  ',
     2'INTEREST DURING CONSTRUCTION *','CONTINGENCY **                '/
      PH2O=H2OCON
C
C     PRINT OUT SYSTEM DESCRIPTION AND HEADINGS
      IPAGE=IPAGE+1
      WRITE(NOUT,5) IPAGE,DATE
    5 FORMAT(1H1,'PAGE ',I4,T67,A8)
      WRITE(NOUT,10) SYSTEM,SCFM,DEGF,PSO2,PH2O,PPMSIN,PPMSOT,SO2OUT
   10 FORMAT ('0',T11,'SYSTEM DESCRIPTION: ',A10//
     2 T11,'SYSTEM VARIABLES:',T31,'SCFM:',F6.0,' AT ',F5.0,' F',/,
     3 T31,'%SO2:',F5.2,/, T31,'%H2O:',F5.1,//,
     4 T11,'SO2 CONCENTRATIONS: INPUT TO SYSTEM:     ',F7.0,' PPM',/,
     5 T31,'OUTPUT FROM SYSTEM: ',F7.0,' PPM  ',F6.0,' LB/HR')
      WRITE(NOUT,15)
   15 FORMAT(T60,5HREQ'D,/T54,'REF.',T60,'REF.',/T54,'YEAR',T60,'YEAR',
     &       T69 ,'REVISED',/T54,5HREQ'D,T60,'INDEX',T70 ,'COST',/T54,
     &       25('-'))
      WRITE(NOUT,20)
   20 FORMAT ('0',T11,'INSTALLED FIELD COSTS',T45,'1981 $',/T11,21(1H-)
     &       ,T43,11(1H-))
C
C     PRINT OUT EQUIPMENT CATEGORY TOTALS
      DO 21 I=1,5
      N=NCEI(I)
C
C     NCEI IS CEI COST INDEX FOR EACH EQUIPMENT CATEGORY
      IF(ISYS.EQ.4.AND.I.LT.3)GO TO 21
      I1=1
      IF(I1 .EQ. 4 .AND. IVENT .EQ. 1) I1=14
      IF(TOTAL(I) .LE. 0) GO TO 21
      WRITE(NOUT,30) IFCLIS(I1),TOTAL(I),IRYR(N),CEI(N),
     & RTOTAL(I)
   21 CONTINUE
C
C     SOME CATEGORY NUMBERS DIFFER DEPENDING ON SYSTEM
      IF ((ISYS.EQ.1).OR.(ISYS.EQ.3)) WRITE(NOUT,30) IFCLIS(6),TOTAL(6)
     &,IRYR(4),CEI(4),RTOTAL(6)
      IF  (ISYS.EQ.2)   WRITE(NOUT,30) IFCLIS(7),TOTAL(6)
     &,IRYR(4),CEI(4),RTOTAL(7)
      IF  (ISYS.EQ.4)   WRITE(NOUT,30) IFCLIS(10),TOTAL(6)
     &,IRYR( 3),CEI( 3),RTOTAL(10)
      IF(ISYS.EQ.4)WRITE(NOUT,30)IFCLIS(12),TOTAL(1)
     &,IRYR(4 ),CEI( 4),RTOTAL(12)
      IF((ISYS.EQ.2.OR.ISYS.EQ.4).AND.LIQUID.EQ.1)
     *    WRITE(NOUT,30)IFCLIS(11),TOTAL(7),IRYR(6 )
     &,CEI(6 ),RTOTAL(11)
   30 FORMAT(' ',T11,A30, F13.0,T54,I4,T61,A3,T66
     &,F13.0)
      WRITE(NOUT,40)
   40 FORMAT (' ',T43,11('-'),T68,11(1H-))
C
C     PRINT OUT EQUIPMENT CATEGORY SUPTOT
      WRITE(NOUT,50) SUBTOT,RSTOT
   50 FORMAT (' ',T32,'SUB-TOTAL ',F13.0,T66,F13.0/)
C
C     PRINT OUT POND TOTALS
      IF(ISOLID .GE. 3 .AND. IVENT .EQ. 0)
     *WRITE(NOUT,30) IFCLIS(8), TOTAL(8),IRYR(5)
     &,CEI(5),RTOTAL(8)
      IF(ISOLID .LT. 3 .OR. IVENT .EQ. 1)
     *WRITE(NOUT,30) IFCLIS(13), TOTAL(8),IRYR(5)
     &,CEI(5),RTOTAL(8)
      IF(TOTAL(9) .GT. 0.)
     &WRITE(NOUT,30) IFCLIS(9), TOTAL(9) ,IRYR(5)
     &,CEI(5),RTOTAL(9)
      WRITE(NOUT,40)
      WRITE(NOUT,60) TOTALD,RTOTD
   60 FORMAT (' ',T27,'DIRECTS TOTAL ',F13.0,T66,F13.0//)
      WRITE(NOUT,70)
   70 FORMAT (' ',T11,'INDIRECT COSTS',/T11,14(1H-))
C
C     PRINT OUT INDIRECTS TOTALS
      DO 71 I=1,3
   71 WRITE(NOUT,75) ICLIST(I),TOTAL(I+9),RTOTAL(I+12)
   75 FORMAT (' ',T11,A30,F13.0,T66,F13.0)
      WRITE(NOUT,40)
      WRITE(NOUT,80) TOTALI,RTOTI
   80 FORMAT (' ',T25,'INDIRECTS TOTAL ',F13.0,T66,F13.0/)
      WRITE(NOUT,81)
   81 FORMAT (' ',T43,11('='),T68,11(1H=))
C
C     PRINT OUT TOTAL CAPITAL COSTS AND COOLING POND LINER COST
      WRITE(NOUT,90) TOTC,RTOTC
   90 FORMAT (' ',T21,'TOTAL CAPITAL COSTS ',F13.0,T66,F13.0)
      CALL SMTRO(ACLNR,100.)
      CALL SMTRO(RACLNR,100.)
      IF(TOTAL(9).GT.0.0)WRITE(NOUT,100)ACLNR,IRYRLN,PACLNR
  100 FORMAT(//' ',T11,'COOLING POND LINER COST    ',F13.0,T54,I4,T61,
     & 'PI',T66,F13.0)
      WRITE(NOUT,110)RCAP,YCON,RICNTG
  110 FORMAT(///T11,'* BASED ON CAPITAL COST OF ',2PF4.1,1H%,
     &' INSTALLED IN ',0PF3.1,' YEARS',/T11,'** ',2PF3.0,1H%)
      RETURN
      END
**
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SPT*SMELTER(1).012(9)
      SUBROUTINE SMTOT2
C
C          THIS SUBROUTINE PRINTS OUT A REPORT LISTING THE QUANTITY
C      OF EACH EQUIPMENT ITEM FOR THE SYSTEM CHOSEN AND ITS INSTALLED
C      COST. EQUIPMENT ITEMS ARE GROUPED BY GENERAL EQUIPMENT CATEGORY.
C
C
      CHARACTER*30 ITEM,DATE*8
      CHARACTER SYSTEM*10
      CHARACTER*30 IFCLIS(15),IFCX
      DIMENSION AC(13),QUAN(4),XC(2,4),XCF(3)
      COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,
     &RICNTG,XC,XCF,RT1,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,IBYPAS,IRET
      COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPMSO2,SO2AB,PPMSIN
     *               ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPMH2O,PPMAIR,
     *               PPMTOT,PPMABU,PPMABN
      COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
     *                JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
      COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
     *                   ,TOTC
      COMMON /COM05/PREC,NXOT,IENTRY,NOUT,NXX4,NXX5,AC,QUAN,
     *     PONCFT,XX4,DEPTH
      COMMON /HEAD/ IPAGE,DATE
C
C     WRITE OUT GENERAL HEADING
      IPAGE=IPAGE+1
      WRITE(NOUT,50) IPAGE,DATE
   50 FORMAT(1H1,'PAGE ',I4,T67,A8,//)
      ITOT=0
      WRITE(NOUT,100)
  100 FORMAT ('0',T6,'EQUIPMENT LISTING',/,T25,'ITEM',T56,'QUANTITY',
     2T66,' INST. COST'/,T25,'----',T56,'--------',T66,'-----------')
C
C     LOOP ON EQUIPMENT CATEGORIES
      DO 1000 I=1,7
C
C     WRITE OUT CATEGORY HEADINGS
      IF (I.EQ.6) GO TO 101
      IF(I.EQ.7) GO TO 106
      II=I
      IF(IVENT .EQ. 1 .AND. I.EQ.4) II=14
      IFCX = IFCLIS(II)
      GO TO 130
  101 IF ((ISYS.EQ.1).OR.(ISYS.EQ.3)) IFCX = IFCLIS(6)
      IF  (ISYS.EQ.2)  IFCX = IFCLIS(7)
      IF  (ISYS.EQ.4)  IFCX = IFCLIS(10)
      GO TO 130
  106 IF(LIQUID.NE.1)GO TO 1000
      IFCX=IFCLIS(11)
  110 FORMAT('0',T6,A30)
  120 FORMAT(A30,2F10.0,F5.0,I5)
C
C     K IS THE NUMBER OF ENTRIES FOR CATEGORY I
  130 K=IPT(I,30)
      IF(K .EQ. 0) GO TO 1000
      ITOT=ITOT+K
      WRITE(NOUT,110) IFCX
      MAX=1000
      IF(ITOT .GT. 30)MAX=30-(ITOT-K)+1
      IF(MAX .NE. 1000) ITOT=0
C
C     LOCATE ALL EQUIPMENT ITEMS FOR CATEGORY I AND PRINT NUMBER
C     AND COST FOR EACH
      DO 200 J1=1,K
      IF(J1 .LT. MAX) GO TO 135
      MAX=1000
      IPAGE=IPAGE+1
      WRITE(NOUT,50) IPAGE,DATE
      WRITE(NOUT,115) IFCX
  115 FORMAT('0',T6,A30,/T10,'(CONT.)')
  135 J=IPT(1,J1)
      IF(J .EQ. 163)GO TO 200
      READ(3'J,120) ITEM,BCOST,BSIZE,F,ICAT
      WRITE(NOUT,140) ITEM,NEQUIP(J),COST(J)
  140 FORMAT (' ',T25,A30,1X,I5,5X,F11.0)
  200 CONTINUE
 1000 CONTINUE
C
C     SPECIAL CASE FOR CITRATE ITEM 163
      IF(ISYS.NE.4)GO TO 240
      WRITE(NOUT,110)IFCLIS(12)
      READ(3'163,120)ITEM
      WRITE(NOUT,140)ITEM,NEQUIP(163),COST(163)
C
C     PRINT OUT POND DIMENSIONS
  240 IF(ISOLID .GT. 2) GO TO 250
C
C     DISPOSAL POND
      IF(ISYS .EQ. 1) PONCFT=PONCFT*1.38/1.47
      DIM=SQRT(PONCFT/DEPTH)
      WRITE(NOUT,300) IFCLIS(13),DIM,DIM,DEPTH
      GO TO 260
C
C     3 DAY EMERGENCY POND
  250 CONTINUE
      DIM= SQRT(PONCFT/10.)
      WRITE(NOUT,300) IFCLIS(8),DIM,DIM,10.
C
C     COOLING POND
  260 IF(TOTAL(9).LE.0.0)GO TO 999
      CPOND = GPM*90.0*4.0
      DIM = SQRT(CPOND/4.)
      WRITE(NOUT,300)IFCLIS(9),DIM,DIM,4.
  300 FORMAT('0', T6,A30/T24,2(F5.0,' FT X '),F3.0,' FT DEEP   1')
  999 RETURN
      END
**
```

```
SPT*SMELTER(1).PON(10)
      SUBROUTINE SMTPON
C
C
C          THIS ROUTINE SIZES AND COSTS DISPOSAL, EMERGENCY, AND
C      COOLING PONDS.
C
C
      CHARACTER SYSTEM*10
      CHARACTER*30 IFCLIS(15)
      DIMENSION AC(13),QUAN(4),XC(2,4),XCF(3),XL(4)
      DIMENSION A(6),B(6),C(6),BRKPT(5),DEPTH(6)
      COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,
     &RICNIG,XC,XCF,RTI,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,IBYPAS,IRET
      COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPHSO2,SO2AB,PPMSIN
     *                ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPHH2O,PPHAIR,
     *                PPHTOT,PPHABU,PPHABN
      COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
     *                 JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
      COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
     *                  ,TOTC
      COMMON /COM05/PREC,NXOT,IENTRY,NOUT,NXX4,NXX5,AC,QUAN,
     *      PONCFT,AELNR,AX5
      COMMON /COOL/ ITWR
      DATA A/3.8971E04,7.2627E04,2.0902E05,2.7377E05,6.2876E05,
     &       1.8016E06/
      DATA B/8.712E05,1.3068E06,3.267E06,3.9204E06,1.06722E07,5.0E07/
      DATA C/.65,.723,.732,.775,.72,.63/
      DATA DEPTH/10.,15.,25.,30.,35.,40./
      DATA BRKPT/6.534E05,1.742E06,2.178E06,3.9204E06,4.5738E06/
      DATA XL/30.,30.,60.,22.4/
      DATA OGPM/0./
      IF(ITWR .EQ. 2) GPM= OGPM
      OGPM= GPM
C
      IF(ISYS .EQ. 1)CASO3=PPHABN*120./56.*.9
      IF(ISYS .EQ. 3)CASO3=PPHABN*120./100.*.85
C
      IF(ISOLID .LE. 2) GO TO 10
C
C     COST 3 DAY EMERGENCY POND ... TOTAL(8)
      PONCFT=SCFM*XL(ISYS)/1000.*.07*60.*72./7.48
      E38=PONCFT/27.
C     E38  -  POND VOL. CU.YD.
      AELNR=SQRT(PONCFT/10.)
      E39=120.*AELNR+(AELNR-26.)**2
C     E39 - POND LINER AREA, SQ.FT.
      TOTAL(8)=E38*6.56+E39*1.56
      CALL SMTRO(TOTAL(8),100.)
      GO TO 18
C
C     COST DISPOSAL POND ... TOTAL(8)
   10 PONCFT=0.
      PNCFTV=0.
      IF(IVENT .EQ. 1) PNCFTV=.27*SCFM/50000.*2000./150.*350.*PLIFE
      IF(IVENT .EQ. 1 .AND. ISOLID .GT. 2)PNCFTV=PNCFTV+10.*SCFM
     &/1000.*.07*60.*24.*3./8.33
```

```
      IF(ISOLID .GT. 2) GO TO 15
      IF(ISYS .EQ. 1) PONCFT=(CASO3+PPHABN*.2)*24.*350.*PLIFE
     &/(0.6*62.4*1.47)
      IF(ISYS .EQ. 3) PONCFT=(CASO3+PPHABN*.55)*24.*350.*PLIFE
     &/(0.6*62.4*1.36)
   15 PONCFT=PNCFTV+PONCFT
C
C     FIND PROPER VOLUME RANGE
      DO 100 I=1,5
         IF(PONCFT .LT. BRKPT(I)) GO TO 200
  100    CONTINUE
      I=6
C
  200 TOTAL(8)=A(I)*(PONCFT/B(I))**C(I)
      CALL SMTRO(TOTAL(8),100.)
      XX5=DEPTH(I)
C
C     COST COOLING POND
   18 IF(PREC .EQ. 0 .AND. LIQUID .EQ. 0) GO TO 30
      IF(ISYS .EQ. 4) GPM= GPM+.0341*SCFM
      IF (ISYS.EQ.2 .AND. LIQUID.EQ.1)GPM=GPM+SO2AB*.05269
      IF(ISYS .EQ. 4 .AND. LIQUID .EQ. 1) GPM= GPM+SO2AB*.00471
      GO TO (20,19),ITWR
C
C     COOLING TOWER
   19 EQUIPS(34)=GPM
      NEQUIP(34)=1
      ACLNR=0.
      TOTAL(9)=0.
      GO TO 30
C
   20 CPOND=GPM*90.*4.
      E40=CPOND/27.
C     E40 - COOLING POND VOL, CU.YD.
      E41=SQRT(GPM*90.)
      ACLNR=(E41*48.)+((E41-10.)**2)*1.56
      TOTAL(9)=E40*2.51+ACLNR
      CALL SMTRO(TOTAL(9),100.)
   30 RETURN
      END
**
```

```
SPT*SMELTER(1).RDR(17)
      SUBROUTINE SMTRDR
C
C          THIS SUBROUTINE READS ALL USER INPUT DATA. METHOD OF
C      INPUT IS DEPENDENT ON ACCESS MODE (IENTRY=1 - BATCH; 0
C      - INTERACTIVE).
C
C
      CHARACTER*1 S,P,V,BY,LSO2,IY,TB,OTE
      CHARACTER*10 SYS(4),DATE*8,D*8,DUM*8
      CHARACTER SYSTEM*10,SYSSAV*10
      CHARACTER*30 IFCLIS(15),CEI*3
      DIMENSION AC(13),QUAN(4),XCI(3),XCF(3),XC(2,4),SE(4)
      COMMON /COMD1/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,RICNTG,
     &XC,XCF,RTI,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,IBYPAS,IRET
      COMMON /COMD2/ACFM,SCFM,DEGF,PSO2,DSO2,PPMSO2,SO2AB,PPMSIN
     *                ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPMH2O,PPMAIR,
     *                PPMTOT,PPMABU,PPMABR
      COMMON /COMD3/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
     *                JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
      COMMON /COMD4/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
     *                 ,TOTC
      COMMON /COMD5/PREC,NXOT,IENTRY,NOUT,NXX4,NXX5,AC,QUAN,
     *          ALPHA,XX4,XX5
      COMMON /COMD6/ IBYR,CEI(6),IRYR(6),RTOTAL(15),RSTOT,
     &          RTOTD,RTOTI,RACLNR,IRYRLN,RTOTC,NCEI(15)
      COMMON /COMD7/SYSSAV,ISAV,IT
      COMMON /CITRAT/ SA,CIT,OIL,SAQ,CITQ,OILQ,SAC,CITC,OILC
      COMMON /INDCOM/ XIND(6)
      COMMON /HEAD/ IPAGE,DATE
      DATA SE/90.,92.,85.,95./
      DATA IY/'Y'/,OTE/'X'/
      DATA SYS/'LIME      ','MGO       ','LIMESTONE ','CITRATE   '/
      NXOT=0
      IEXIT=0
      EFF=0.0
      CALL ADATE(D,DUM)
      SUBSTR(DATE,1,2)=SUBSTR(D,1,2)
      SUBSTR(DATE,3,1)='/'
      SUBSTR(DATE,4,2)=SUBSTR(D,3,2)
      SUBSTR(DATE,6,1)='/'
      SUBSTR(DATE,7,2)=SUBSTR(D,5,2)
C
C     FIND MAXIMUM ESCALATION YEAR
      READ(15'25) MAXY
      IF (IENTRY.EQ.1) GO TO 100
      IF(IENTRY .EQ. 0) GO TO 1
      NOUT= 6
      IENTRY= 1
      GO TO 100
    1 DO 2 I=1,6
    2 XIND(I)=0.0
C
C ** INTERACTIVE INPUT **
      PRINT *, '  ENTER ONE SYSTEM NAME: '
      READ(5,10)SYSTEM
   10 FORMAT(A10)
C
C     DETERIMINE SYSTEM-TYPE INDEX (ISYS)
   15 DO 20 I=1,4
```

```
      IF(SYSTEM.NE.SYS(I))GO TO 20
      ISYS=I
      IF (IENTRY.EQ.1) GO TO 110
      GO TO 32
   20 CONTINUE
C
C     IF NO MATCH FOR SYSTEM TERMINATE PROGRAM
      IEXIT=1
      IF(IENTRY .EQ. 1) GO TO 110
      GO TO 30
   32 CONTINUE
      PRINT *, '  ENTER ALL OF THE FOLLOWING VARIABLES.'
      PRINT *, '  SEPARATE EACH BY A BLANK SPACE OR COMMA:'
      PRINT *,' SCFM  DEGF, %SO2, % MOISTURE, %EFFICIENCY, PLANT LIFE '
      READ(5,*)SCFM,DEGF,PSO2,H2OCON,EFF,PLIFE
      PRINT *, ' ENTER NUMBER OF DAYS STORAGE OF FRESH ABSORBANT '
      READ(5,*) NDAYS
      PRINT *, ' REQUIRE BYPASS TO STACK ?'
      READ(5,65) BY
      PRINT *, '  VENTURI(Y/N) ?, STACK(Y/N) ?,'
      PRINT *, ' PRECOOLER (Y/N) ?  SEPARATE BY COMMAS '
      READ(5,65) V,S,P
   65 FORMAT(3(A1,1X))
C
C     NO SOLIDS DISPOSAL (ISOLID=7) FOR MGO OR CITRATE
      ISOLID=7
      IF(ISYS .EQ. 2 .OR. ISYS .EQ. 4) GO TO 24
      PRINT *, ' '
      PRINT *, ' ENTER TYPE OF    1 - POND'
      PRINT *, ' SOLIDS DISPOSAL 2 - THICKENER/POND'
      PRINT *, '                 3 - THICKENER/VACUUM FILTER'
      PRINT *, '                 4 - THICKENER/CENTRIFUGE'
      PRINT *, '                 5 - OXIDATION/THICKENER/CENTRIFUGE'
      PRINT *, '                     (GYPSUM)  '
      PRINT *, '                 6 - OXIDATION/THICKENER/VACUUM FILTER'
      PRINT *, '                     (GYPSUM)'
      PRINT *, ' '
      READ(5,*) ISOLID
      IF(ISOLID .LT. 1 .OR. ISOLID .GT. 6) ISOLID=1
C
C     NO LIQUID SO2 FOR LIME OR LIMESTONE
      LSO2='N'
      GO TO 25
   24 PRINT *, ' PRICE LIQUID SO2 ?'
      READ(5,65) LSO2
   25 PRINT *, ' '
      PRINT *, ' ENTER TYPE OF INSTALLATION FACTOR'
      PRINT *, '    1 - EASY OR NEW INSTALLATION'
      PRINT *, '    2 - MODERATELY DIFFICULT INSTALLATION'
      PRINT *, '    3 - DIFFICULT INSTALLATION'
      PRINT *, ' '
      READ(5,*) IRET
      ISTACK=1
      IF(S .EQ. 'Y') ISTACK=2
      LIQUID=0
      IF(LSO2 .EQ. 'Y') LIQUID=1
      IVENT=0
      IF(V .EQ. IY) IVENT=1
      IBYPAS=0
      IF(BY .EQ. IY) IBYPAS=1
      PREC=0.
      IF(P .EQ. IY) PREC=1.
      PRINT *, ' ENTER THE FOLLOWING VARIABLES FOR CAPITAL COSTS'
      PRINT *, '  (SEPARATE BY COMMAS)'
      PRINT *, ' '
      PRINT *, ' YEARS TO CONSTRUCT,'
      PRINT *, ' CONTINGENCY (%) '
      READ(5,*) YCON,RICNTG
      RICNTG=RICNTG*.01
C
      PRINT *, ' '
      PRINT *, ' ENTER THE FOLLOWING VARIABLES FOR ANNUAL COSTS'
      PRINT *,' (SEPARATE BY COMMAS) '
      PRINT *, ' WATER ($/MGAL),'
      PRINT *, ' ELECTRICITY (MILLS/KWH),'
      PRINT *, ' LABOR ($/MANHOUR) '
      READ(5,*) ACF
      IF(ISYS .NE. 2) GO TO 27
      PRINT *, ' '
      PRINT *, ' OIL ($/GAL) '
      READ(5,*) OIL
   27 CONTINUE
      PRINT *, ' '
      PRINT *, ' INSURANCE & TAXES (%),'
      PRINT *, ' CAPITAL COST (%) '
      READ(5,*) RTI,RCAP
      RCAP=RCAP*.01
      RTI=RTI*.01
C
C     INPUT RAW MATERIALS (DEPENDING ON SYSTEM)
      PRINT *, ' '
      IF(ISYS .NE. 4) GO TO 45
      PRINT *, ' ENTER RAW MATERIAL COSTS ($/TON)'
      PRINT *, ' CITRATE '
      READ(5,*) CIT
      XC(1,4)=CIT
      PRINT *, ' SODA ASH '
      READ(5,*) SA
      GO TO 40
   45 PRINT *, ' RAW MATERIAL -- ',SYSTEM
      PRINT *, '       COST ($/TON) '
      READ(5,*) XC(1,ISYS)
      IF(ISYS .EQ. 1) XC(2,1)=XC(1,1)
      IF(ISYS .NE. 3) GO TO 40
      PRINT *, ' FIXATION CHEMICAL -- LIME'
      PRINT *, '       COST ($/TON) '
      READ(5,*) XC(2,3)
   40 PRINT *, ' '
      IF(ISYS .EQ. 1 .OR. ISYS .EQ. 3 .OR. LIQUID .NE. 1) GO TO 35
      PRINT *, ' ENTER SULFURIC ACID COST'
      PRINT *, ' '
      READ(5,*) XC(2,ISYS)
   35 CONTINUE
C
```

```
      PRINT *, ' 6 CEI REFERENCE YEARS BY PROCESS AREA'
      PRINT *, ' (IF ESCALATION IS DESIRED PAST 'MAXY' THE USER SHOULD'
      PRINT *, ' FOLLOW THE YEAR WITH A COMMA AND THE DESIRED INDEX.)'
      PRINT *, ' '
      PRINT *, ' PLANT COST '
      READ(5,67) IRYR(1),XIND(1)
      PRINT *, ' EQUIPMENT, MACHINERY, & SUPPORTS '
      READ(5,67) IRYR(2),XIND(2)
      PRINT *, ' FAPRICATED EQUIPMENT '
      READ(5,67) IRYR(3),XIND(3)
      PRINT *, ' PROCESS MACHINERY '
      READ(5,67) IRYR(4),XIND(4)
      PRINT *, ' CONSTRUCTION LABOR '
      READ(5,67) IRYR(5),XIND(5)
      PRINT *, ' PUMPS & COMPRESSORS '
      READ(5,67) IRYR(6),XIND(6)
   67 FORMAT(I2,1X,F7.0)
C
      PRINT *, ' '
      PRINT *, ' ENTER TYPE OF OUTPUT LISTING'
      PRINT *, ' 1 - CAPITAL & ANNUAL COSTS'
      PRINT *, ' 2 - CAPITAL & ANNUAL COSTS WITH EQUIPMENT LISTING'
      PRINT *, ' '
      READ(5,*) NXOT
C
C     IF SYSTEM TYPE CHANGES ASK USER IF TABULAR LISTING FOR
C     CURRENT SYSTEM IS DESIRED
      IF(SYSTEM .EQ. SYSSAV) GO TO 28
      WRITE(6,200) SYSTEM
  200 FORMAT(' DO YOU WISH A TABULAR LISTING FOR ',A10)
      READ(5,65) TB
C
   28 PRINT *, ' OUTPUT MODE:  1 - TERMINAL'
      PRINT *, '               2 - OFFLINE PRINTER'
      PRINT *, ' '
      READ(5,*) IO
      NOUT=IO
      IF(IO .EQ. 1) NOUT=6
      IF(SYSTEM .EQ. SYSSAV) GO TO 50
   30 IF(OTB .EQ. IY) CALL SMTSMY
      IF(IEXIT .EQ. 1) GO TO 9000
      SYSSAV=SYSTEM
      ISAV=ISYS
      OTB=TB
      GO TO 50
C
  100 CONTINUE
C
C ** BATCH INPUT **
C
C     2 CARDS
C
C
      READ(5,12)SYSTEM,SCFM,DEGF,PSO2,H2OCON,EFF,PLIFE,NDAYS,XCF(1),
     &XCF(2),OIL,XCF(3),YCON,PICNTG,XCI,RTI,RCAP,ISTACK,LIQUID,IRET,
     &PREC,IBYPAS,IVENT,ISOLID,NXOT,ISUM,IRYR,XIND
   12 FORMAT(A10,F8.0,F5.0,2F4.2,2F3.1,I3,5X,F3.2,F3.1,F3.2,F4.2,5X,
     XF3.1,F2.2,/,F6.2,2F5.2,2X,F3.2,F3.1,3X,3I1,F1.0,5I1,5X,6I2,6F4.1)
      ISTACK=ISTACK+1
      RCAP=RCAP*.01
      RTI=RTI*.01
      GO TO 15
  110 IF(ISYS .EQ. 1) XCI(2)=XCI(1)
      XC(1,ISYS)=XCI(1)
      XC(2,ISYS)=XCI(2)
      IF(ISYS .LT. 4) GO TO 115
      CIT=XCI(1)
      SA=XCI(3)
  115 IF(ISUM .EQ. 1) CALL SMTSMY
      IF(IEXIT .EQ. 1 ) GO TO 9000
      SYSSAV=SYSTEM
      ISAV=ISYS
C
C     CHECK FOR INVALID OPTIONS
   50 IF(NOUT .NE. 2 .AND. NOUT .NE. 6) NOUT=2
      IF(ISYS .EQ. 2 .OR. ISYS .EQ. 4)ISOLID=7
      IF(ISYS .EQ. 1 .OR. ISYS .EQ. 3) LIQUID=0
      DO 55 I=1,6
      MAXY = MAXY - 1900
      IF(IRTK(I) .GT.MAXY.AND. XIND(I) .EQ. 0) STOP ' ** BAD COST INDEX'
   55 CONTINUE
      IF(DEGF .GE. 400.) PREC=1.
      IF(EFF .GT. SE(ISYS))EFF=SE(ISYS)
      IF(ISTACK .NE. 1 .AND. ISTACK .NE. 2) ISTACK=2
      IF(IRET .LT. 1 .OR. IRET .GT. 3) IRET=1
C
C     IF END OF RUN RESET SUMMARY FILE
      IF(IEXIT .NE. 1) GO TO 9999
 9000 CONTINUE
 9999 RETURN
      END
**
```

```
SMT*SMELTER(1).RO(1)
                SUBROUTINE SMTRO(XX,RO)
                INTEGER*4 IX,KX,JX,LX
                IX=XX/1000000.
                JX=(XX-(IX*1000000.))/1000.
                KX=XX-(IX*1000000.) - (JX*1000.)
                LX=RO/2.
                KX=(KX+LX)/(LX*2)
                XX=(IX*1000000.)+(JX*1000.)+(KX*RO)
                END
**
```

```
SMT*SMELTER(1).RPT(4)
     SUBROUTINE SMTRPT
C
C         THIS SUBROUTINE ACTS AS A DRIVER FOR COSTING AND REPORT
C     WRITING ROUTINES.
C
C
     CHARACTER SYSTEM*10
     CHARACTER*30 IFCLIS(15),XC(2,4),XCF(3)
     DIMENSION AC(13),QUAN(4)
     COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID
    &,RICNTG,XC,XCF,RTI,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,
    &IBYPAS,IRET
     COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPHSO2,SO2AB,PPMSIN
    *                        ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPHH2O,PPHAIR,
    *                        PPHTOT,PPHABU,PPHABN
     COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
    *                          JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
     COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
    *                          ,TOTC
     COMMON /COM05/PREC,NXOT,IENTRY,NOUT,NXX4,NXX5,AC,QUAN,
    *             ALPHA,XX4,XX5
C
C    CALCULATE CAPITAL COSTS BASED ON SIZE AND NUMBER OF EQUIPMENT
C    ITEMS
     CALL SMTCST
C
C    ADJUST COSTS TO REFERENCE YEARS (INPUT)
     CALL SMTESC
C
C    WRITE CAPITAL COST SUMMARY LISTING
     CALL SMTOT1
C
C    WRITE EQUIPMENT LISTING (IF DESIRED)
     IF(NXOT .GE. 2) CALL SMTOT2
C
C    CALCULATE ANNUAL COSTS
     CALL SMTAC1
C
C    WRITE OUT ANNUAL COSTS
     CALL SMTAC2
C
C    SAVE CAPITAL AND ANNUAL COST TOTALS FOR FUTURE TABULAR LISTING
     CALL SMTSAV
     RETURN
     END
**
```

```
SPT*SMELTER(1).SAV(4)
            SUBROUTINE SMTSAV
            CHARACTER SYSTEM*10
            CHARACTER*30 IFCLIS(15),CEI*3
            DIMENSION AC(13),QUAN(4),XC(2,4),XCF(3)
            COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,
           &RICNTG,XC,XCF,RTI,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,IBYPAS,IRET
            COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPHSO2,SO2AB,PPMSIN
           *                   ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPHH2O,PPHAIR,
           *                   PPHTOT,PPHABU,PPHABN
            COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
           *                    JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
            COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
           *                      ,TOTC
            COMMON /COM05/PREC,NXOT,IENTRY,NOUT,NXX4,NXX5,AC,QUAN,
           *          ALPHA,XX4,XX5
            COMMON /COM06/ IBYR,CEI(6),IRYR(6),RTOTAL(15),RSTOT,
           * RTOTD,RTOTI,RACLNR,IRYLN,RTOTC,NCEI(15)
            ISMY=((ISYS-1)*50)+1
            READ(10'ISMY)RSMY
            RSMY=RSMY+1.0
            NSMY=RSMY
            IREC=ISMY+NSMY
            WRITE(10'IREC)SCFM,DEGF,PSO2,RTOTC,AC(13)
            WRITE(10'ISMY)RSMY
            RETURN
            END
**
```

```
SMT.SMELTER(1).SMY(8)
      SUBROUTINE SMTSMY
      CHARACTER SYSTEM*10,SYSSAV*10
      CHARACTER*30 IFCLIS(15),DATE*8
      DIMENSION SMRY(5)
      DIMENSION AC(13),QUAN(4),XC(2,4),XCF(3)
      COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID,
     &RICNTE,XC,ACF,RTI,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT,IBYPAS,IRET
      COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPMSO2,SO2AB,PPMSIN
     *                    ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPMH2O,PPMAIR,
     *                    PPMTOT,PPMABU,PPMABN
      COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
     *                    JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
      COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
     *                      ,TOTC
      COMMON /COM05/PREC,NXOT,IENTRY,NOUT,NXX4,NXX5,AC,QUAN,
     *         ALPHA,XX4,XX5
      COMMON /HEAD/ IPAGE,DATE
      COMMON /COM07/ SYSSAV,ISAV,I1
      IPAGE = IPAGE + 1
      WRITE(NOUT,5) IPAGE,DATE
    5 FORMAT(1H1,'PAGE ',I4,T67,A8)
      WRITE(NOUT,10) SYSSAV
   10 FORMAT ('0',T11,'SYSTEM DESCRIPTION: ',A10)
      WRITE(NOUT,15)
   15 FORMAT(//4X,'SCFM  TEMP  %SO2   CAPITAL ',6X,'OPERATING',/)
      ISMY=((ISAV-1)*50)+1
      READ(10'ISMY)RSMY
      IF(RSMY.GT.0.0)GO TO 30
      WRITE(NOUT,20)
   20 FORMAT(/5X,'** SUMMARY FILE EMPTY **')
      GO TO 999
   30 NSMY=RSMY
      DO 50 I=1,NSMY
      IF(MOD(I,40) .NE. 0) GO TO 35
      IPAGE=IPAGE+1
      WRITE(NOUT,5) IPAGE,DATE
      WRITE(NOUT,11) SYSSAV
   11 FORMAT('0',T11,'SYSTEM DESCRIPTION:',A10,/T31,'(CONT.)')
      WRITE(NOUT,15)
   35 IREC=ISMY+I
      READ(10'IREC)SMRY
      WRITE(NOUT,40)SMRY
   40 FORMAT(2X,F7.0,1X,F4.0,1X,F5.2,2(1X,F12.0))
   50 CONTINUE
  999 RETURN
      END
**
```

```
SPT*SMELTER(1).TNK(1)
      SUBROUTINE SMTTNK(A,NA,SA,NB)
C
C     A    = TOTAL VOLUME IN TANK
C     NA = NUMBER OF TANKS
C     SA = SURFACE AREA OF TANK
C     NB = NUMBER OF AGITATORS
C     SQFT = SQUARE FOOT OF TANK AREA (FOR COSTING)
C
      CUFT=A
  110 IF (CUFT .LT. 6283.)DIAM=(CUFT/(0.25*3.14159))**(1.0/3.0)
      IF (CUFT .GE. 6283.)DIAM=SQRT(CUFT/(5.*3.14159))
      IF(DIAM.LT.75.0)GO TO 120
      CUFT=A/NA
      NA=NA+1
      GO TO 110
  120 SA=3.14159*DIAM*DIAM/4.0
      NB=(SA/300.0)+1.0
      SA=SA/NB
      NB=NB*NA
      IF (CUFT .LT. 6263.)SQFT=5./4.*3.14159*DIAM**2
      IF (CUFT .GE. 6263.)SQFT=3.1459*DIAM*(20.+DIAM/4.)
      A=SQFT
      RETURN
      END
**
```

```
SMT*SMELTER(1).VEN(2)
      SUBROUTINE SMTVEN
      DIMENSION XC(2,4),XCF(3),AC(13),QUAN(4)
      CHARACTER SYSTEM*10
      CHARACTER*30 IFCLIS(15)
      COMMON /COM01/SYSTEM,ISYS,EFF,IEXIT,ISTACK,LIQUID
     &,RICNT6,XC,XCF,RTI,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT
     &,IBYPAS
      COMMON /COM02/ACFM,SCFM,DEGF,PSO2,DSO2,PPHSO2,SO2AB,PPMSIN
     *                 ,PPMSOT,SO2OUT,H2OCON,PH2O,DH2O,PPHH2O,PPHAIR,
     *                 PPHTOT,PPHABU,PPHABN
      COMMON /COM03/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
     *                  JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
      COMMON /COM04/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
     *                   ,TOTC
      COMMON /COM05/PREC,NXOT,IENTRY,NOUT,NXX4,NXX5,AC,QUAN,
     *           ALPHA,XX4,XX5
C
C *** VENTURI ***
C
C
C     VENTURI
      DEGREE=DEGF
      IF(PREC .EQ. 1 .OR. DEGREE .EQ. 400.)DEGREE=127.
      EQUIPS(202)=SCFM*((460.+DEGREE)/530.)*.5*((460.+DEGREE)/2460.)
     &**(-.378)
      NEQUIP(202)=2
C
C     CIRCULATION TANK
      NEWAT=(.112-PPHH2O/PPHAIR)*PPHAIR/(8.33*60.)
      EQUIPS(203)=(EQUIPS(202)/1000.*10+NEWAT)*15.*1.1/7.48
      NEQUIP(203)=2
      CALL SMTTNK (EQUIPS(203),NEQUIP(203),EDUMMY,NDUMMY)
C
C     FEED PUMPS
      EQUIPS(204)=EQUIPS(202)/1000.*10.
      NEQUIP(204)=4
C
C     PH ADJUSTING TANK AND AGITATORS
      EQUIPS(205)=EQUIPS(204)*0.07*60.*2.*1.1/7.48
      NEQUIP(205)=1
      CALL SMTTNK(EQUIPS(205),NEQUIP(205),EQUIPS(206),NEQUIP(206))
C
C     PUMP TO POND
      EQUIPS(207)=0.07*EQUIPS(204)
      NEQUIP(207)=2
C
C     RETURN WATER PUMP
      EQUIPS(208)=.99*EQUIPS(207)-EQUIPS(207)*.004*1.25
      NEQUIP(208)=2
```

```
SPT*SMELTER(1).VEN(2)
      SUBROUTINE SMTVEN
      DIMENSION XC(2,4),XCF(3),AC(13),QUAN(4)
      CHARACTER SYSTEM*10
      CHARACTER*30 IFCLIS(15)
      COMMON /COMC1/SYSTEM,ISYS,EFF,IFXIT,ISTACK,LIQUID
     &,RICNTG,XC,XCF,RTI,RCAP,PLIFE,NDAYS,ISOLID,YCON,IVENT
     &,IBYPAS
      COMMON /COMC2/ACFM,SCFM,DEGF,PSO2,DSO2,PPMSO2,SO2AE,PPMSIN
     *                 ,PPMSOT,SO2OLT,H2OCON,PH2O,DH2O,PPHH2O,PPHAIR,
     *                PPHTOT,PPHABU,PPHABN
      COMMON /COMC3/EQUIPS(300),NEQUIP(300),COST(300),TOTAL(15),
     *                 JMIN(4,10),JMAX(4,10),IFCLIS,IPT(9,30)
      COMMON /COMC4/GPM,DUCTL,E38,E39,E40,E41,SUBTOT,TOTALD,TOTALI
     *                   ,TOTC
      COMMON /COMC5/PREC,NXOT,IENTRY,NOUT,NXX4,NXX5,AC,QUAN,
     *          ALPHA,XX4,XX5
C
C *** VENTURI ***
C
C
C     VENTURI
      DEGREE=DEGF
      IF(PREC .EQ. 1 .OR. DEGREE .EQ. 400.)DEGREE=127.
      EQUIPS(202)=SCFM*((460.+DEGREE)/530.)*.5*((460.+DEGREE)/2460.)
     &**(-.378)
      NEQUIP(202)=2
C
C     CIRCULATION TANK
      NEWAT=(.112-PPHH2O/PPHAIR)*PPHAIR/(8.33*60.)
      EQUIPS(203)=(EQUIPS(202)/1000.*10+NEWAT)*15.*1.1/7.48
      NEQUIP(203)=2
      CALL SMTTNK (EQUIPS(203),NEQUIP(203),EDUMMY,NDUPMY)
C
C     FEED PUMPS
      EQUIPS(204)=EQUIPS(202)/1000.*10.
      NEQUIP(204)=4
C
C     PH ADJUSTING TANK AND AGITATORS
      EQUIPS(205)=EQUIPS(204)*0.07*60.*2.*1.1/7.48
      NEQUIP(205)=1
      CALL SMTTNK(EQUIPS(205),NEQUIP(205),EQUIPS(206),NEQUIP(206))
C
C     PUMP TO POND
      EQUIPS(207)=0.07*EQUIPS(204)
      NEQUIP(207)=2
C
C     RETURN WATER PUMP
      EQUIPS(208)=.99*EQUIPS(207)-EQUIPS(207)*.004*1.25
      NEQUIP(208)=2
C
C     FEED WATER TANK
      EQUIPS(209)=(EQUIPS(207)*.996+NEWAT)*1.1/7.48
      NEQUIP(209)=1
      CALL SMTTNK (EQUIPS(207),NEQUIP(207),EDUMMY,NDUPMY)
C
C     FEED WATER PUMP
```

```
      EQUIPS(210)=EQUIPS(207)*.0956*NEWAT
      NEQUIP(210)=2
C
C     DUCTING TO SCRUBBER
      DUCTD1= 2.*SQRT(SCFM*587./530./3500./3.14159)
      DUCTL1=100
      EQUIPS(211)=DUCTD1*DUCTL1*3.14159*16.
      NEQUIP(211)=1
C
      RETURN
      END
**
```

EQUIPMENT FACTOR
FILE LIST

```
SCREW CONVEYOR ON STORAGE SILO17000.     150.      0.61    1   1
STORAGE SILO                  95000.     1270.     0.78    1   2
PNEUMATIC CONVEYOR            111870.    128.0     0.56    1   3
BAGHOUSE ON STORAGE SILO      20200.     700.      0.65    1   4
ROTARY FEEDER                 3900.      1.00      1.0     1   5
DAY SILO                      95000.     1270.     0.78    1   6
BUCKET ELEVATOR               51950.     15.       0.65    1   7
SLAKER                        38300.     8.        0.57    2   8
24-HR HOLD TANK               28700.     1570.     0.41    2   9
AGITATOR                      4160.      300.      0.5     2  10
PUMP FROM DILUTION TANK       4650.      50.       0.25    2  11
12-HR DILUTION TANK           28700.     1570.     0.41    2  12
AGITATOR                      4160.      300.      0.5     2  13
COOLING CHAMBER               329700.    17325.    0.52    3  14
DUCT FROM ESP-INSULATED       1.01       1.0       1.0     4  15
HOLD TANK FOR COOLING CHAMBER 28700.     1570.     0.41    3  16
PUMP FOR COOLING POND/TOWER   4650.      50.       0.25    3  17
PUMP TO COOLING CHAMBER       6350.      50.       0.30    3  18
ABSORBER                      194413.    138260.   1.0     4  19
ABSORBER RECIRCULATION TANK   28700.     1570.     0.41    4  20
AGITATOR                      4160.      300.      0.50    4  21
PUMP FOR ABSORBER             7440.      50.       0.25    4  22
                                                               23
MIST ELIMINATOR               7642.      116400.   1.0     4  24
STACK FAN                     179400.    116400.   0.68    4  25
SOOT BLOWER                   8200.      1.0       1.0     4  26
DUCT FROM COOLING CHAMBER     0.78       1.0       1.0     4  27
SUMP PUMP                     1462.      1.0       1.0     4  28
BLOWER FOR REHEATER           23922.     66780.    0.68    5  29
DUCT TO STACK-INSULATED       1.01       1.0       1.0     5  30
REHEATER                      39870.     38849.    0.8     5  31
STACK                         972431.    111918.   0.20    5  32
DUCT FOR BYPASS-INSULATED     1.01       1.        1.      5  33
COOLING TOWER                 147000.    17020.    0.82    3  34
PH TANK                       28700.     1570.     0.41    6  35
AGITATOR                      4160.      300.      0.5     6  36
OXIDATION TANK                28700.     1570.     0.41    6  37
PUMP TO THICKENER             4650.      50.       0.25    6  38
THICKENER                     57274.     60.       1.0     6  39
SOLIDS HOLD TANK              28700.     1570.     0.41    6  40
AGITATOR                      4160.      300.      0.5     6  41
CENTRIFUGE                    98000.     11260.    0.58    6  42
SCREW CONVEYOR                17000.     150.      0.61    6  43
LIQUID HOLD TANK              28700.     1570.     0.41    6  44
                                                               45
PUMP TO LIQUID HOLD TANK      7440.      50.       0.25    6  46
DUMP TRUCK                    60000.     1.        1.      6  47
PIPING TO AND FROM POND       52600.     163200.   0.455   6  48
PIPING FRM THKNR TO & FRM POND36100.     153000.   0.384   6  49
BUCKET ELEVATOR               51950.     15.       0.83    1  50
CALCINER HOPPER               14290.     1800.     0.68    1  51
PNEUMATIC CONVEYOR            111870.    128.      0.56    1  52
WEIGH FEEDER                  3840.      1.        1.0     1  53
BUCKET ELEVATOR               51950.     15.       0.83    1  54
VIRGIN MGO SILO               30900.     241.      0.66    1  55
DAY SILO                      30900.     241.      0.66    1  56
PNEUMATIC CONVEYOR            111870.    128.      0.56    1  57
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                                                                     58
ROTARY FEEDER                   3900.       1.        1.0        1   59
SLURRY TANK                     28700.      1570.     0.41       2   60
AGITATOR                        4160.       300.      0.5        2   61
SLURRY HEATER                   13680.      314.      0.9        2   62
12-HR DILUTION TANK             28700.      1570.     0.41       2   63
AGITATOR                        4160.       300.      0.5        2   64
PUMP FROM SLURRY TK TO DIL TK   4650.       50.       0.25       2   65
                                                                     66
                                                                     67
                                                                     68
                                                                     69
LIQUID CYCLONE                  2600.       80.       0.85       6   70
SURGE TANK                      25700.      1570.     0.41       6   71
AGITATOR                        4160.       300.      0.5        6   72
CENTRIFUGE                      98000.      11260.    0.58       6   73
LIQUID OVERFLOW HOLD TANK       28700.      1570.     0.41       6   74
AGITATOR                        4160.       300.      0.5        6   75
SCREW CONVEYOR FROM CENTRIFUGE17000.        150.      0.61       6   76
ROTARY DRYER                    259740.     16960.    0.6        6   77
BUCKET ELEVATOR                 51950.      15.       0.83       6   78
MGSO3 STORAGE SILO              6000.       35.       0.78       6   79
WEIGH FEEDER                    3840.       1.0       1.0        6   80
BELT CONVEYOR                   6300.       6000.     0.81       6   81
CYCLONE SEPARATOR(ROT DRYER)    9351.       6000.     0.8        6   82
BAGHOUSE ON CYCLONE SEPARATOR   16900.      9000.     0.65       6   83
                                                                     84
CALCINER                        584428.     10180.    0.6        6   85
ROTARY FEEDER                   3900.       1.        1.0        6   86
BLOWER                          9091.       12100.    0.3        6   87
AIR/AIR HEAT EXCHANGER          49471.      15260.    0.65       6   88
WASTE HEAT EXCHANGER            9676.       15260.    0.8        6   89
CYCLONE SEPARATOR(CALCINER)     20390.      15260.    0.9        6   90
REGENERATED MGO SILO            30900.      241.      0.66       1   91
OIL STORAGE TANK                28700.      1570.     0.41       6   92
OIL HEATER                      13680.      314.      0.9        6   93
OIL PUMP TO ROTARY DRYER        4650.       50.       0.25       6   94
DUCT TO CALCINER-INS            1.01        1.0       1.0        6   95
SPRAY CHAMBER                   62156.      15430.    0.8        7   96
DRYING COLUMN                   56065.      7500.     0.65       7   97
PUMP AT DRYING COLUMN           7440.       50.       0.25       7   98
ACID COOLER                     25977.      107.      0.65       7   99
BLOWER TO DRYING COLUMN         13304.      15430.    0.68       7  100
COMPRESSOR                      385507.     6500.     0.90       7  101
STORAGE REC IVER/TANK           110000.      3638.2    .41        7  102
PUMP TO STORAGE                 7440.       50.       0.25       7  103
DUCT TO LIQ SO2-HAIRPIN COOLER1.01          1.0       1.0        7  104
                                                                    105
                                                                    106
                                                                    107
                                                                    108
IN GROUND HOPPER                36600.      1.0       1.0        1  109
CONVEYOR TO STORAGE-SLOPED      60200.      39.       0.81       1  110
CONVEYOR TO STORAGE-HORIZONTAL3980.         1.        1.0        1  111
CONVEYOR TO 3-DAY SILO          60200.      39.       0.81       1  112
STONE COLUMN                    22338.      1.        1.         1  113
FRONT END LOADER                76500.      1.        1.         1  114
```

3-DAY SILO	114000.	1630.	0.86	1
ROTARY FEEDER	3900.	1.	1.	1
MAGNETIC DEVICE	4560.	1.	1.	1
BELT CONVEYOR	2330.	20.	0.81	1
BUCKET ELEVATOR	51950.	20.	0.83	1
BAGHOUSE ON 24-HOUR SILO	20200.	700.	0.65	1
DAY SILO	114000.	1630.	0.86	1
WEIGH FEEDER	3840.	1.0	1.0	1
BALL MILL	90372.	8.	0.65	2
CLASSIFIER	13290.	8.	0.57	2
24-HOUR HOLD TANK	28700.	1570.	0.41	2
AGITATOR	4160.	300.	0.5	-
PUMP TO DILUTION TANK	4650.	50.	0.25	2
12-HR DILUTION TANK	28700.	1570.	0.41	2
AGITATOR	4160.	300.	0.5	2
ABSORBER	160300.	1140.	0.79	4
ABSORBER RETENTION TANK	28700.	1570.	0.41	4
AGITATOR	4160.	300.	0.50	4
PUMP TO ABSORBERS	10160.	50.	0.3	4
PUMP FROM ABSORBER	7440.	50.	0.25	4
FEED PREHEATER	143300.	2276.	0.65	6
ABSORBATE COOLER	67800.	1526.	0.65	6
STRIPPER	73400.	460.	0.645	6
REBOILER	101500.	1277.	0.65	6
CONDENSER	184700.	4066.	0.83	6
70% ACID RECYCLE PUMP	7440.	50.	0.25	7
98% ACID RECIRCULATION PUMP	7440.	50.	0.25	7
DRYING TOWER	26000.	689.	0.65	7
ACID COOLER	12600.	94.	0.65	7
REFRIGERATION UNIT	225900.	83.6	0.66	7
LIQUID SO2 PUMP	10160.	50.	0.30	7
STORAGE RECEIVER/TANK	110000.	5685.2	0.41	7
BLOWER	3300.	689.	0.68	7
DUCTING TO DRYER	0.78	1.00	1.00	7
PURGE STREAM REGENERATION	290900.	5487.	0.35	1
BAGHOUSE ON DAY SILO	20200.	700.	0.65	1
SCREW CONVEYOR ON DAY SILO	9800.	150.	0.61	1
ABSORBENT MAKE-UP PUMP	7440.	50.	0.30	2
CONVEYOR HOPPER	7300.	36.	0.68	1
BAGHOUSE ON 3-DAY SILO	20200.	700.	0.65	1

					172
ABSORBENT MAKE-UP PUMP	7440.	50.	0.25	2	173
THICKENER HOLD TANK	28700.	1570.	0.41	6	174
AGITATOR	4156.	2000.	0.5	6	175
PUMP TO OXIDATION TANK	7440.	50.	0.25	6	176
COMPRESSOR	171000.	5500.	0.5	6	177
PUMP FROM THICKENER	4650.	50.	0.25	6	178
PUMP FROM SOLIDS HOLD TANK	4650.	50.	0.25	6	179
VACUUM FILTER	175000.	817.	0.63	6	180
BELT CONVEYOR	6000.	6000.	.81	6	181
					182
PUMP FROM LIQUID HOLD TANK	4650.	50.	0.25	6	183
PUMP FROM POND	4650.	50.	0.25	6	184
					185
BAGHOUSE ON REGEN SILO	20200.	700.	0.65	1	186
BAGHOUSE ON VIRG AND DAY SILO	20200.	700.	0.65	1	187
PUMP FROM LIQ OVFL HOLD TANK	4650.	50.	0.25	2	188
WEIGH FEEDER	3840.	1.0	1.0	1	189
DUCT FROM ROTARY DRYER-INS	1.01	1.	1.	6	190
DUCT FROM CYC SEP TO BAGHSE	.78	1.	1.	6	191
					192
DUCT FROM DAY SILO TO BAGHSE	1.25	1.	1.	1	193
DUCT FROM CALC-REFRAC LINED	56.5	1.	1.	6	194
DUCT FROM UNE-REFRAC LINED	56.5	1.	1.	6	195
PUMP TO SPRAY CHAMBER	4650.	50.	0.25	7	196
OIL PUMPS TO CALCINER	4560.	50.	0.25	6	197
ABSORBENT MAKE-UP PUMP	4650.	50.	0.25	2	198
					199
					200
					201
VENTURI	750000.	500000.	1.14	4	202
CIRCULATION TANK	104100.	1570.	0.41	4	203
FEED PUMP	7440.	50.	0.25	4	204
PH ADJUSTING TANK	104100.	1570.	0.41	4	205
AGITATOR	4160.	300.	0.5	4	206
PUMP TO POND	4650.	50.	0.25	4	207
RETURN WATER PUMP	4650.	50.	0.25	4	208
FEED WATER TANK	28700.	1570.	0.41	4	209
FEED WATER PUMP	4560.	50.	0.25	4	210
DUCT TO ABSORBER	.78	1.	1.	4	211
PUMP TO 98% ACID STORAGE TANK	10160.	50.	0.30	7	212
98% ACID STORAGE TANK	104100.	1570.	0.41	7	213
PUMP FROM 98%ACID STORAGE TANK	10160.	50.	0.3	7	214
70% ACID HOLD TANK	104100.	1570.	0.41	7	215
PUMP FROM 70% ACID HOLD TANK	10160.	50.	0.3	7	216
70% ACID STORAGE TANK	104100.	1570.	0.41	7	217
PUMP TO 98% ACID STORAGE TANK	10160.	50.	0.30	7	218
98% ACID STORAGE TANK	104100.	1570.	0.41	7	219
PUMP FROM 98%ACID STORAGE TANK	10160.	50.	0.30	7	220
70% ACID HOLD TANK	104100.	1570.	0.41	7	221
PUMP FROM 70% ACID HOLD TANK	10160.	50.	0.30	7	222
70% ACID STORAGE TANK	104100.	1570.	0.41	7	223

ESCALATION FACTOR
FILE LIST

125.7	123.8	122.7	122.9	137.3	125.6
132.3	130.4	130.3	127.9	146.2	133.2
137.2	135.4	136.3	132.1	152.2	135.9
144.1	141.8	142.5	137.8	157.9	139.8
165.4	171.2	170.1	160.0	163.3	175.7
182.4	194.7	192.2	184.7	168.6	208.3
192.1	205.8	200.8	197.5	174.2	220.9
204.1	220.9	216.6	211.6	178.2	240.2
218.8	240.3	238.6	228.3	185.9	257.5
238.7	264.7	261.7	250.0	194.9	280.4
261.1	292.2	291.6	271.8	204.3	330.3
290.1	318.7	317.1	296.5	232.3	381.8

SAMPLE OUTPUTS

```
PAGE   81
                                                                 04/02/82
                                   INPUT SUMMARY
                                   --------------

 SYSTEM NAME: LIME          SCFM: 150000.@ 230 DEG F     1.0% SO2  1.0% MOISTURE
                            EFFICIENCY: 80%            PLANT LIFE: 10.0 YEARS
                            NUMBER OF DAYS STORAGE OF FRESH ABSORBANT: 20

                            OPTIONAL EQUIPMENT INCLUDED
                                 BYPASS TO STACK: NO
                                 VENTURI:         YES
                                 STACK:           NO
                                 PRECOOLER:       NO

                            SOLIDS DISPOSAL METHOD USED
                               _ 1 - DIRECT TO POND
                               _ 2 - THICKENER/POND
                               X 3 - THICKENER/VACUUM FILTER
                               _ 4 - THICKENER/CENTRIFUGE
                               _ 5 - OXIDATION/THICKENER/CENTRIFUGE
                                       (GYPSUM)
                               _ 6 - OXIDATION/THICKENER/VACUUM FILTER
                                       (GYPSUM)

                            INSTALLATION FACTOR
                               _ 1 - EASY OR NEW INSTALLATION
                               _ 2 - MODERATELY DIFFICULT INSTALLATION
                               X 3 - DIFFICULT INSTALLATION

              COST OPTIONS: RAW MATERIAL COSTS ($/TON)
                            LIME              : 60.00


                            CAPITAL COST:  9.5%
                            TAXES & INSURANCE:  2.0%
                            CONTINGENCY:  5.0%
                            YEARS TO CONSTRUCT: 2.0
                            WATER ($/MGAL):  .90
                            ELECTRICITY (MILLS/KWH): 30.0
                            LABOR ($/MANHOUR): 8.90

        CE PROCESS AREA                              REF YEAR   INDEX
        ---------------------------------------------------------------
        PLANT COST(PC)                                  80       261.5
        EQUIPMENT, MACHINERY, & SUPPORTS(EMS)           80       292.5
        FABRICATED EQUIPMENT(FE)                        80       291.6
        PROCESS MACHINERY(PM)                           80       271.0
        CONSTRUCTION LABOR(CL)                          80       204.3
        PUMPS & COMPRESSORS(PC)                         80       330.3
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      SYSTEM DESCRIPTION: LIME

      SYSTEM VARIABLES:   SCFM: 150000. AT  230. F
                          %SO2: 1.00
                          %H2O:  1.0

      SO2 CONCENTRATIONS: INPUT TO SYSTEM:      10000. PPM
                          OUTPUT FROM SYSTEM:    1139. PPM   2979. LB/HR
                                                      REQ'D
                                                 REF.  REF.
                                                 YEAR  YEAR      REVISED
                                                 REQ'D INDEX      COST
                                                 -------------------------

      INSTALLED FIELD COSTS                1981 $
      ---------------------              -----------
      MATERIALS HANDLING                   1241000.  80    PM         1134300.
      FEED PREPARATION                      667100.  80    FE          613500.
      SO2 SCRUBBING/VENTURI                6705300.  80    FE         6166100.
      REHEAT AND STACK                      435100.  80    FE          400100.
      SOLIDS DISPOSAL                      1018400.  80    PM          930800.
                                         -----------                -----------
                             SUB-TOTAL    10066900.                   9244800.

      DISPOSAL POND(VENTURI)                 87900.  80    CL           77300.
                                         -----------                -----------
                         DIRECTS TOTAL    10154800.                   9322100.


      INDIRECT COSTS
      --------------
      INDIRECTS (31.25% OF DIRECT)         3173400.                   2913200.
      INTEREST DURING CONSTRUCTION *        823000.                    755500.
      CONTINGENCY **                        707600.                    649500.
                                         -----------                -----------
                       INDIRECTS TOTAL     4704000.                   4318200.

                                         ===========                ===========
                   TOTAL CAPITAL COSTS    14858800.                  13640300.


      * BASED ON CAPITAL COST OF  9.5% INSTALLED IN 2.0 YEARS
      **  5.%
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EQUIPMENT LISTING

	ITEM	QUANTITY	INST. COST
MATERIALS HANDLING			
	SCREW CONVEYOR ON STORAGE SILO	3	17100.
	STORAGE SILO	3	472500.
	PNEUMATIC CONVEYOR	1	145100.
	BAGHOUSE ON STORAGE SILO	1	157300.
	ROTARY FEEDER	5	35000.
	DAY SILO	2	71700.
	BUCKET ELEVATOR	2	252400.
	BAGHOUSE ON DAY SILO	1	86700.
	SCREW CONVEYOR ON DAY SILO	1	3200.
FEED PREPARATION			
	SLAKER	2	180600.
	24-HR HOLD TANK	2	142600.
	AGITATOR	4	34300.
	PUMP FROM DILUTION TANK	2	20300.
	12-HR DILUTION TANK	2	183700.
	AGITATOR	6	52400.
	ABSORBENT MAKE-UP PUMP	2	53200.
SO2 SCRUBBING/VENTURI			
	DUCT FROM ESP-INSULATED	1	160900.
	ABSORBER	2	1756900.
	ABSORBER RECIRCULATION TANK	1	124500.
	AGITATOR	2	30100.
	PUMP FOR ABSORBER	8	537300.
	MIST ELIMINATOR	2	82000.
	STACK FAN	1	859200.
	SOOT BLOWER	4	123300.
	SUMP PUMP	1	5500.
	VENTURI	2	1515600.
	CIRCULATION TANK	2	682000.
	FEED PUMP	4	265300.
	PH ADJUSTING TANK	1	284400.
	AGITATOR	1	10800.

```
 SO2 SCRUBBING/VENTURI
     (CONT.)
                              PUMP TO POND                      2          42200.
                              RETURN WATER PUMP                 2          42500.
                              FEED WATER TANK                   1          23100.
                              FEED WATER PUMP                   2          45100.
                              DUCT TO ABSORBER                  1         114600.
 REHEAT AND STACK
                              BLOWER FOR REHEATER               1          65300.
                              DUCT TO STACK-INSULATED           1         162300.
                              REHEATER                          1         207500.
 SOLIDS DISPOSAL
                              PUMP TO THICKENER                 2          24300.
                              THICKENER                         1         207800.
                              SOLIDS HOLD TANK                  1          45300.
                              AGITATOR                          1           6600.
                              LIQUID HOLD TANK                  1          47000.
                              DUMP TRUCK                        3         180000.
                              THICKENER HOLD TANK               1          65500.
                              AGITATOR                          4          10000.
                              PUMP FROM THICKENER               2          24100.
                              PUMP FROM SOLIDS HOLD TANK        2          24100.
                              VACUUM FILTER                     2         322400.
                              BELT CONVEYOR                     1          38800.
                              PUMP FROM LIQUID HOLD TANK        2          22500.
 EMERGENCY POND
                              135. FT X  135. FT X 10. FT DEEP  1
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        SYSTEM DESCRIPTION: LIME

        SYSTEM VARIABLES:   SCFM: 150000.
                            %SO2: 1.00
        SO2 CONCENTRATIONS: 80. % ABSORBED
                               QUANTITY     UNIT COST           ANNUAL COST

        RAW MATERIALS
        LIME                  7.17 T/H 8400 HR/YR   60.00 $/TON     3612900.
        FIXATION CHEMICALS     .29 T/H 8400 HR/YR   60.00 $/TON      145700.
           (PH CONTROL)

        UTILITIES
        WATER                 173. GPM 8400 HR/YR    .90 $/MGAL       78500.
        ELECTRICITY          1566. KW  8400 HR/YR  30. MILLS/KWH     394600.

        OPERATING LABOR
        DIRECT LABOR                 5 MEN/SHIFT   8.90 $/H/MAN      390200.
        SUPERVISON            15% OF DIRECT LABOR                     58500.

        MAINTENANCE
        LABOR AND MATERIALS    4% OF FIXED INVESTMENTS               545600.
        SUPPLIES              15% OF LABOR AND MATERIALS              81800.

        OVERHEAD
        PLANT                 50% OF OPERATION & MAINTENANCE         538100.
        PAYROLL               20% OF OPERATING LABOR                  89800.

        FIXED COSTS
        DEPRECIATION          (10.0%)
        TAXES & INSURANCE     ( 2.0%)
        CAPITAL COST          ( 9.5%)
                           SUM= 21.5% OF FIXED INVESTMENT           2932700.

        TRUCKING COSTS        $27.85/10 CUBIC YARDS                  437900.
                                                                  ==========
                              TOTAL ANNUAL COST                     9306300.
                           (BASED ON REVISED COSTS)
```